REPORT RESUMES

ED 020 615 EC 002 658

RESEARCH BULLETIN. NUMBER 3.

AMERICAN FOUNDATION FOR THE BLIND, NEW YORK, N.Y.

PUB DATE AUG 63

EDRS PRICE MF-$1.00 HC-$9.00 223P.

DESCRIPTORS- *EXCEPTIONAL CHILD RESEARCH, *VISUALLY HANDICAPPED, ETIOLOGY, TAXONOMY, BLIND, VISUALLY HANDICAPPED MOBILITY, MOBILITY AIDS, SENSORY AIDS, SENSORY EXPERIENCE, RESEARCH METHODOLOGY, READING, VISUAL PERCEPTION, KINESTHETIC PERCEPTION, WORKSHOPS, CONFERENCE REPORTS, ADJUSTMENT (TO ENVIRONMENT), ENVIRONMENTAL INFLUENCES, MACHINE TRANSLATION, ELECTROMECHANICAL AIDS, LEGISLATION,

RESEARCH STUDIES RELEVANT TO SOME ASPECT OF VISUAL IMPAIRMENT ARE CONTAINED IN THE BULLETIN. D.M. BAUMANN AND OTHERS REPORT ON THE COLLAPSIBLE CAN, AND T.L. DEFAZIO AND T.B. SHERIDAN ANALYZE THE VIBRATIONS OF THE CANE. J.J. GIBSON CONSIDERS SENSITIVITY, AND J. MICKUNAS, JR., AND T.B. SHERIDAN DISCUSS THE OBSTACLE COURSE IN MOBILITY EVALUATION OF THE BLIND. ALSO INCLUDED ARE THE FOLLOWING--(1) I.F. LUKOFF AND M. WHITEMAN ON INTERVENING VARIABLES AND ADJUSTMENT, (2) H. GOLDSTEIN ON THE NEED FOR SENSORY DEVICES MARKET RESEARCH, (3) J.R. HOCHSTIM ON THREE INFORMATION GATHERING STRATEGIES WITH SOCIOMEDICAL VARIABLES, (4) F.S. COOPER ON READING MACHINES, (5) M.M. GERMANOV ON APPARATUS FOR READING BY THE BLIND OF ORDINARY TYPOGRAPHIC TEXTS, (6) O.G. SELFRIDGE ON VISUAL PATTERN RECOGNITION, AND (7) F.A. WEBSTER ON ACOUSTICAL CONTROL OF AIRBORNE INTERCEPTION BY BATS. FIVE MEN OFFER SHORT DISCUSSIONS ON THE DEFINITION OF BLINDESS--I.F. SCHLOSS, R.E. HOOVER, A.E. BRALEY, J.W. JONES, AND MD. GRAHAM. ALSO INCLUDED ARE THE REPORT OF THE WORKSHOP ON CLASSIFICATION OF CAUSES OF BLINDNESS AND EXCERPTS FROM THE PROCEEDINGS OF THE WORKSHOP ON NOMENCLATURE OF COMMUNICATIVE DISORDERS. THE ARTICLES PROVIDE THEIR OWN REFERENCE LISTS, FIGURES AND TABLES. THIS DOCUMENT IS AVAILABLE FROM THE AMERICAN FOUNDATION FOR THE BLIND, 15 WEST 16TH STREET, NEW YORK, NEW YORK 10011, FOR $2.50. (JD)

96

[redacted] ERIC

ED020615

EC 000 770 -
EC 000 784

13

RESEARCH BULLETIN

Number 3 August 1963

AMERICAN FOUNDATION FOR THE BLIND
15 WEST 16 STREET NEW YORK 11, N.Y.

EC 002 658

RESEARCH BULLETIN

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

Number 3 August 1963

Compiled by the
DIVISION of RESEARCH and STATISTICS

AMERICAN FOUNDATION FOR THE BLIND
15 WEST 16 STREET NEW YORK 11.N.Y

Price $2.50 per issue

PREFATORY NOTE

The American Foundation for the Blind, as a matter of course, peruses and evaluates a considerable number of articles, reports and manuscripts. Students occasionally submit their thesis or dissertation for possible publication. A Foundation staff member often encounters a research report or statistics which, in his opinion, merits wider dissemination. In some cases, the Foundation initiates or contracts for a research project and is naturally interested in publishing the findings.

Of these various papers, a few may be fortunate enough to find their way into journals not widely circulated. Others, because of their subject matter or length, may never be published.

For this reason, the Division of Research and Statistics of the American Foundation for the Blind publishes a Research Bulletin, composed both of original manuscripts and of previously published articles. The Research Bulletin appears from time to time and contains sociological, psychological and technological papers of interest primarily to research personnel, and secondarily, to those interested in the general improvement of services to the visually handicapped.

Personnel of the Division of Research and Statistics, together with other specialists on the Foundation staff, constitute an informal editorial board. Papers must be either directly or indirectly relevant to some aspect or problem of visual impairment, and must meet generally accepted research criteria. Since these are the only standards for selection, the articles published herein do not necessarily reflect the opinion of the Trustees and Staff of the American Foundation for the Blind.

We earnestly solicit contributions from all scientific fields and welcome all reaction to published articles.

M. Robert Barnett
Executive Director

TABLE OF CONTENTS

Page

I THE COLLAPSIBLE CANE PROJECT
by D.M. Baumann, R. Gerstley, L.A. Neuman, D.S. Nokes and R. Ochsner 1 770

II VIBRATION ANALYSIS OF THE CANE
by T.L. DeFazio and T.B. Sheridan 13 771

III THE USEFUL DIMENSIONS OF SENSITIVITY
by James J. Gibson 15 772

IV USE OF AN OBSTACLE COURSE IN EVALUATING MOBILITY OF THE BLIND
by J. Mickunas, Jr. and T.B. Sheridan 35 773

V INTERVENING VARIABLES AND ADJUSTMENT: AN EMPIRICAL DEMONSTRATION
by Irving F. Lukoff and Martin Whiteman 55 774

VI THE NEED FOR SENSORY DEVICES MARKET RESEARCH
by Hyman Goldstein 66

VII COMPARISON OF THREE INFORMATION-GATHERING STRATEGIES IN A POPULATION STUDY OF SOCIO-MEDICAL VARIABLES
by Joseph R. Hochstim 72 775

VIII REVIEW AND SUMMARY OF READING MACHINES
by Franklin S. Cooper 84 776

IX APPARATUS FOR THE BLIND TO BE USED IN READING ORDINARY TYPOGRAPHIC TEXTS (POLYPHONIC AND TACTILE)
by M.M. Germanov 94 777

X VISUAL PATTERN RECOGNITION: THE PROBLEMS AND PROMISE
by Oliver G. Selfridge 105 778

XI IMPLICATIONS OF ALTERING THE DEFINITION OF BLINDNESS
by Irvin P. Schloss 111 779

VISUAL EFFICIENCY AS A CRITERION OF SERVICE NEEDS
by Richard E. Hoover, M.D. 116

THE PROBLEM OF DEFINITION OF BLINDNESS
by A.E. Braley, M.D. 119 780

PROBLEMS IN DEFINING AND CLASSIFYING BLINDNESS
by John Walker Jones 123 78

TOWARD A FUNCTIONAL DEFINITION OF BLINDNESS
by Milton D. Graham 130 78

XII ACTIVE ENERGY RADIATING SYSTEMS: THE BAT AND ULTRASONIC PRINCIPLES ACOUSTICAL CONTROL OF AIRBORNE INTERCEPTIONS BY BATS by Frederic A. Webster 134

XIII REPORT OF WORKSHOP ON CLASSIFICATION OF CAUSES OF BLINDNESS MODEL REPORTING AREA FOR BLINDNESS STATISTICS 200

XIV EXCERPTS FROM THE PROCEEDINGS OF THE WORKSHOP ON NOMENCLATURE OF COMMUNICATIVE DISORDERS 209

I

THE COLLAPSIBLE CANE PROJECT

by

D.M. Baumann, R. Gerstley, L.A. Neuman, D.S. Nokes and R. Ochsner

EDITOR'S NOTE:

This paper was based on the "Evaluation Report on Work in Progress on Sensory Aids and Prosthetics," Report No. 8768-3, Department of Mechanical Engineering, Massachusetts Institute of Technology, October 31, 1962. The following work was sponsored by the Department of Health, Education and Welfare, Office of Vocational Rehabilitation (contract SAV-1004-61). Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

The collapsible cane project came into being at the Mobility Research Conference held at the Massachusetts Institute of Technology on October 11-13, 1961, jointly sponsored by the American Foundation for the Blind, Office of Vocational Rehabilitation, Seeing Eye, M.I.T. and the Veterans Administration. The meeting was attended by practitioners in the area of mobility training, mobility researchers and mobility aid users.

During the course of the conference many techniques now under study or development were discussed. Throughout these discussions the new techniques were continually compared to the existing mobility aids, the cane and the dog. The comments pertaining to the canes revealed that one of the predominant disadvantages of the cane was the fact that the most acceptable canes, based upon length, strength, durability and balance were not collapsible. After more detailed questioning of the cane-using participants, it was found that in many situations a cane user would prefer to be able to collapse his cane so it could be carried in pocket or purse. Several types of collapsing canes are available; however each seems to have some undesirable characteristics in the extended position. The primary problem seems to be that the joints of the presently available canes become loose after some short lifetime and lose their ability to transmit information to the user. Some of the canes are simply an individual leg of a camera tripod that was not designed for impact loading and very frequent and prolonged use.

At the end of the conference it was summarily determined that, aside from any new or exotic ranging device, a very great need exists for a sturdy, long life, collapsible cane that is mechanically equivalent to the duraluminum long cane when it is extended but which would collapse to less than a foot in length. Furthermore, the collapsing and extending operation should not be difficult or time consuming. In the collapsed position the cane should readily fit in a gentleman's inside coat pocket or a lady's handbag. It would be advantageous if the cane could have a variable extended length so it could be fully extended for travel in relatively clear spaces and only partially extended in congested areas.

It is agreed that cost is certainly a factor that should also be part of the specification of a collapsible cane. However, it was decided that rather than to restrict the cost at this stage of the project and thus be insensitive to possible configurations that may be insignificantly more expensive, the cost of the product should be disregarded during the initial stages of the development. Later, methods of reducing the cost should be investigated. In the past there have been strong feelings expressed that a cane should cost less than five dollars. Certainly this is true but there is also the factor of useful life of the cane to consider. Also, sighted individuals do purchase eyeglasses at costs in excess of twenty-five dollars and even the blind are furnished with dogs that cost an order of magnitude more than the canes. It was thus determined that the proper procedure was to find out how "good" a cane could be developed and then to compromise the cost if necessary.

The collapsible cane project was therefore initiated as a junior project by R. Gerstley, L.A. Neuman, D.S. Nokes and R. Ochsner, all students in the Department of Mechanical Engineering at Massachusetts Institute of Technology. The project was divided up into several portions. Each student worked on a separate portion and meetings were held weekly to coordinate the efforts. This first junior project is considered to be only a first phase of the solution of the collapsible cane project. The next phase will be to construct improved prototypes to be tested under simulated and actual conditions.

Four different cane configurations were evaluated by each of the four students. Excerpts from their reports are given here.

The Friction Joint Canes. (R. Gerstley)

A cane was made of five sections of type 304 stainless steel with one section each of 1/2, 9/16, 5/8, 11/16 and 3/4 inch diameter tubing. Mr. Gerstley found that the 304 was the only steel readily available in these tubing sizes but would have preferred type 410 heat treatable steel if more time had been available for its procurement.

Each of the tubes were relieved except for a small portion at the end and a ring was sweat soldered to the end to make a section as is shown in Fig. 12. The extended length is 51 inches and collapsed length of the five sections was 11 inches. About 10 pounds of force was required to extend or collapse the particular cane that was built. However, the cane also became looser with use because the material was unhardenable.

The problem areas with this type of construction are in the accurate control of tolerances and the desirability of a harder and thus more wear resistant material. A special order of 410 stainless steel would improve this type of cane. The main disadvantages are related to the forces needed to extend the cane as they must of

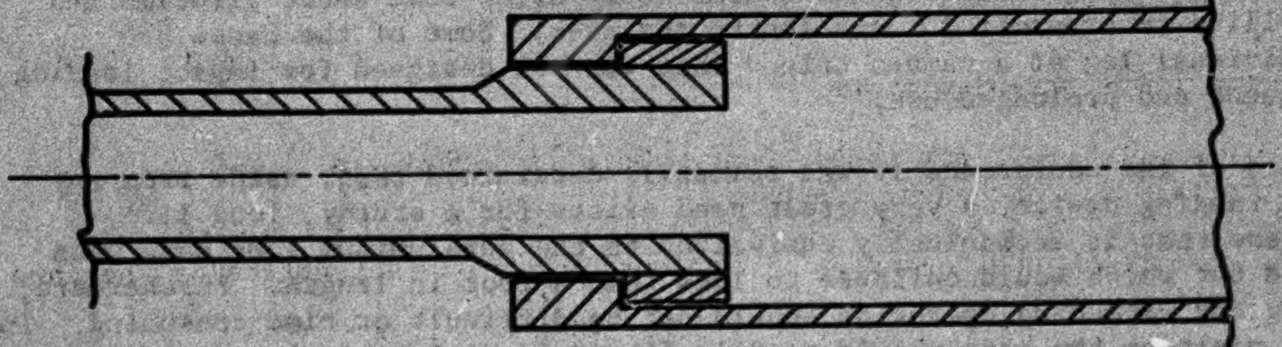


Fig. 12. Sample Friction Joint.

necessity be greater than the force to be placed on the cane when extended. Various methods of locking the joints by bayonet or screw configurations were investigated but none were tested in the available time.

The Spiral Cane (L.A. Neuman)

The spiral cane is a helically coiled strip of beryllium-copper. The strip used was eight feet by three inches by 0.005 inches, wrapped in a spiral to make a wand 50 inches long when extended. The collapsed length is thus three inches plus the cane tip for a total length of about four inches. (Shown in Fig. 13)

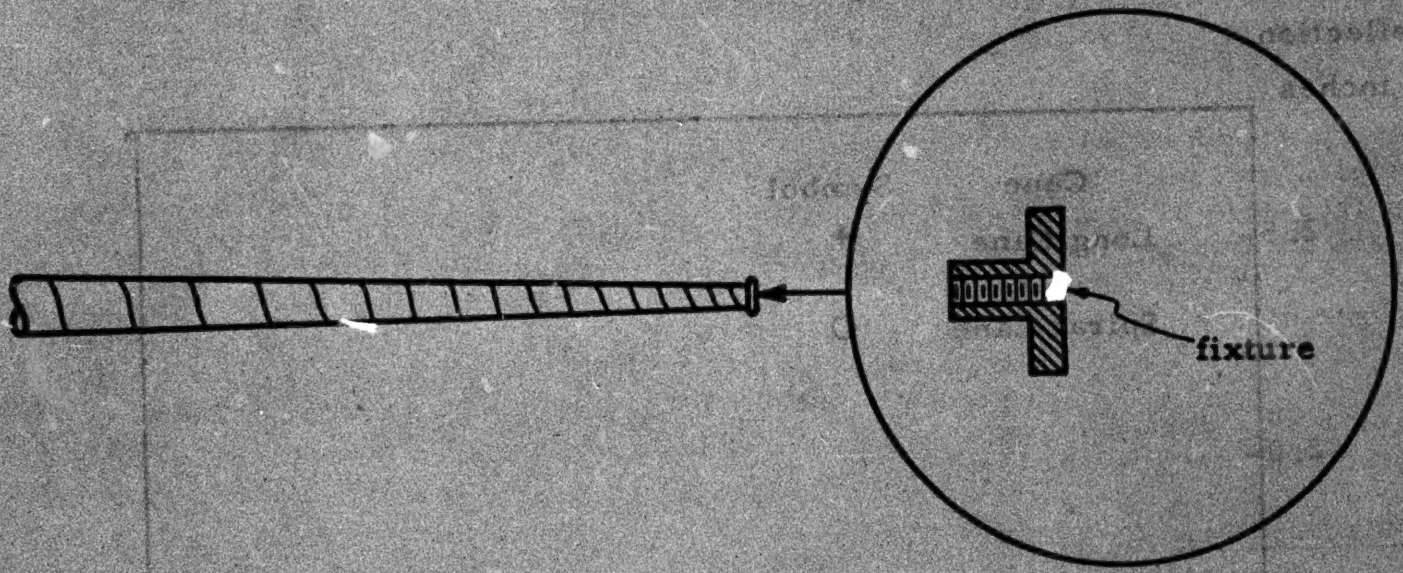


Fig. 13. Spiral Cane Extended

A Description of the Spiral Cane

There is a fixture soldered in the bottom that is threaded for the standard cane tip. At present, the cane is held rigid in the extended position, by locking its maximum diameter with a pipe clamp. It is collapsed into a metal can with a screw top. Total weight is ten ounces.

The cane is heat treated with its equilibrium in the extended position. This was done so that the blind person need not do too much adjusting when he extends it. All he needs to do is twist the cane for about one turn to tighten the coils and lock it. In the locked position, the cane is almost twice as stiff as the long cane (see Fig. 14). The heat treatment of the cane was found to be best as follows:

(i) To anneal - 1450°F for one half hour.

(ii) Form in the annealed state.

(iii) To temper - 600°F for three hours. This is actually a precipitation hardening process.

Heat treatment results in the formation of various oxides on the surface of the cane. These are taken off as follows:

(i) Fifteen minutes immersion in sulfuric acid, 30 percent solution by volume, at 160°F.

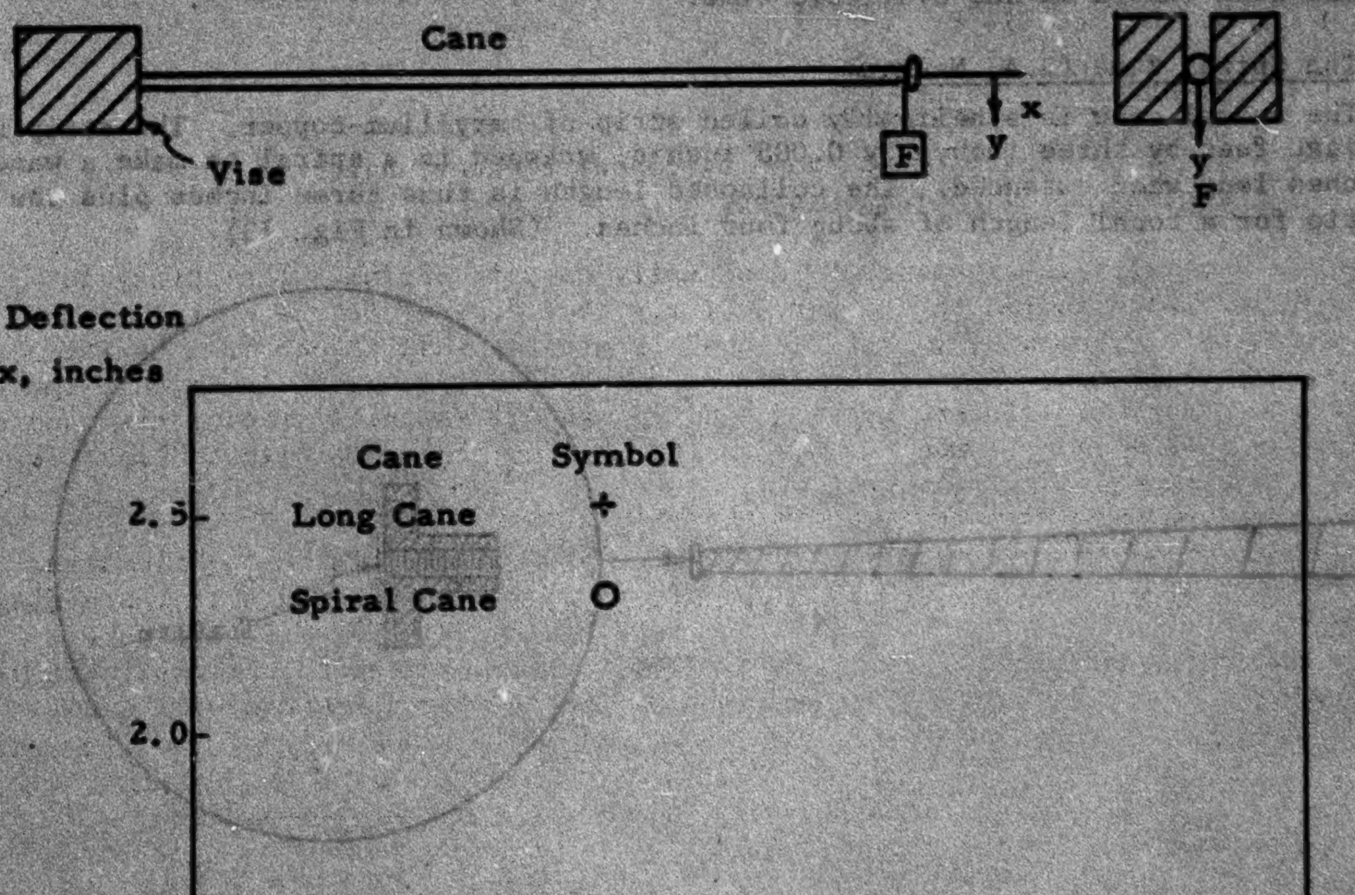


Fig. 14. Force-Deflection Measurements.

(ii) Rinse in hot water.

(iii) One minute immersion in nitric acid, 20 percent solution by volume, at 110°F.

(iv) Rinse in hot water.

(v) Final polishing can be done by copper cleaner, Ajax and water, or similar metal polish or soap.

This process results in a cane that is actually one big spring. The spring is completely variable in length. A particularly good feature of the spiral is that it is relatively unbreakable. A force that is greater than it can take as its elastic limit will cause some slipping and some bending of the coils so that the spiral cane breaks by slipping apart. A blind man who is familiar with his cane can just unwind it and then rewind it back to its original form. A slight "kink" is left, but the cane is still operative.

A final note of caution must be expressed about the manufacturing technique of step (ii) on page 3. In coiling the cane, each coil of succeedingly increasing diameter should be further spaced from the coil before it. This is necessary because the collapsed circumference of a coil equals the extended circumference plus the spacing. A smaller spacing along a line of increasing diameters will cause binding when the cane is collapsed. (See Fig. 15)

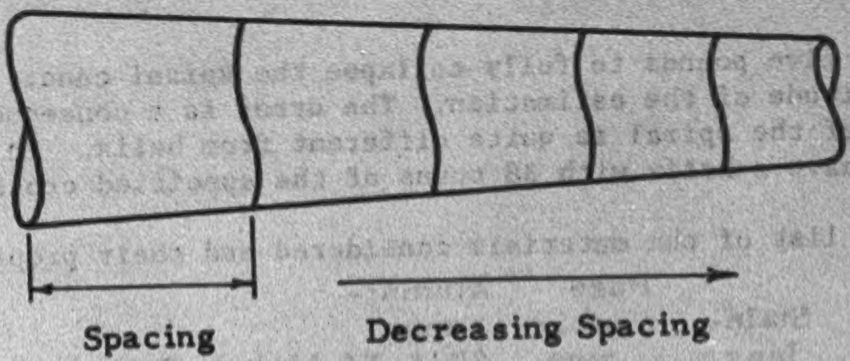


Fig. 15. Spiral Cane.

Selection of Materials

The choice of the material used presented a major problem. Many materials were considered before the final choice was made. The initial choice of material was brass, but when it was decided that the cane should have its equilibrium position in the extended position, brass was rejected as it was found experimentally that the diameter that brass would have to be rolled to, so that its elastic spring back gives the desired position, is too small to make. Since brass cannot be heat treated, it was rejected in favor of a metal that could be. Table 1 shows a tabulation of all the materials considered and their properties which were compared.

Beryllium-copper was chosen for the following reasons:

(i) It can be heat treated.

(ii) It is non-corrosive.

(iii) It has very good friction properties, i.e., it slides over itself in the non-lubricated state quite easily, while aluminum and all steels need considerable lubrication to do as well. This property is extremely important, as binding is a problem which is quite bad in the spring steel model tried.

(iv) Alloy 25 which was used has a yield strength of 175,000 psi, which makes it quite strong for its weight.

(v) Its shear modulus is 2/3 that of stainless steel, and it therefore takes approximately 2/3 the force to collapse a beryllium-copper cane that it would take to collapse a stainless steel cane. The approximation was made from the analysis of a helical spring with a rectangular cross-section. That is,

$$F = \frac{yGt^3(0.56\,t + b)}{5.575\,D_m{}^3 n}$$

where

y is the change in length, 46 inches
G is the shear modulus, 7×10^6 psi
t is the thickness of the material, 0.005 inches
D_m is the mean diameter, 3/4 inch
n is the number of turns in the spring, 38
b is the width of the material, 3 inches
F theoretical = 1.35 lbs.

It actually takes about five pounds to fully collapse the spiral cane. This is within an order of magnitude of the estimation. The error is a consequence of the fact that the geometry of the spiral is quite different from helix. In fact, it would be impossible to have a helix with 38 turns of the specified cross-section.

The following is a list of the materials considered and their properties:

	Spring Steel	Stainless	Pure aluminum	Aluminum 2024-T4	Alclad	Brass	Be-Cu
Heat Treatment	high temp	high temp	none	low temp	low temp	none	low temp
Shear Modulus $\times 10^6$ psi	11.9	10.6	3.7	3.9	3.8	6.0	7.0
Max, yield Strength $\times 10^{-3}$ psi	188	145	21	47	42	80	175
Friction Properties	poor	poor	poor	poor	poor	good	good
Corrosion Resistance	poor	good	good	good	good	good	good
Specific Gravity	7.85	7.85	2.7	2.77	2.77	8.5	8.92

The fixture on the top of the cane is at present a pipe clamp that is removed from the cane and clamped onto the can into which the cane is collapsed for storage. The main problem with this design is the inconvenience because there are loose parts to it which the blind person might possibly drop; the clamp, the can, the screw top. Because the cane is changing its diameter as it is changing length, and because the coils rotate with respect to the cane axis at the same time, any permanent attachment to the cane is not simple. Before this approach can be utilized more fully a permanently attached clamping device and an integrated retaining mechanism for holding the cane in the collapsed condition must be developed.

The Triangular Cane (D.S. Nokes)

The triangular cane is the result of a search for a shape that has a large section modulus and thus is rigid, but that rests into a small rectangular package that can fit the pocket or purse. By a unique placement of hinges, the triangular tube sections can be folded together to make a rectangular package. (See Fig. 16.)

The triangular section used to construct a prototype cane is shown in Fig. 17. Notice that the material used in this case was SAE 1010 steel. Actually 410 stainless steel was again preferred but the time required for a special order exceeded the length of the term project. It is suggested that 5056-H18 aluminum alloy would also be a suitable material for the triangular section because it could be formed as an extruded shape. The aluminum also has an excellent strength to weight ratio and good corrosion resistance. A 5/8 inch tube of the aluminum would have a maximum bending moment of 20 feet-pounds. The hinges, cable and tensioning bar should be made from 410 stainless steel heat treated to a tensile strength of 200,000 psi. This is necessary for wear and high strength in these parts. (See Fig. 18.) The total weight of the aluminum cane with the stainless accessories should be approximately six ounces.

Notice that the cable is captured at each joint so that it is always at the apex of the triangle opposite the hinge. When this cable is tightened by means of the toggle on the tensioning bar, the sections become rigid.

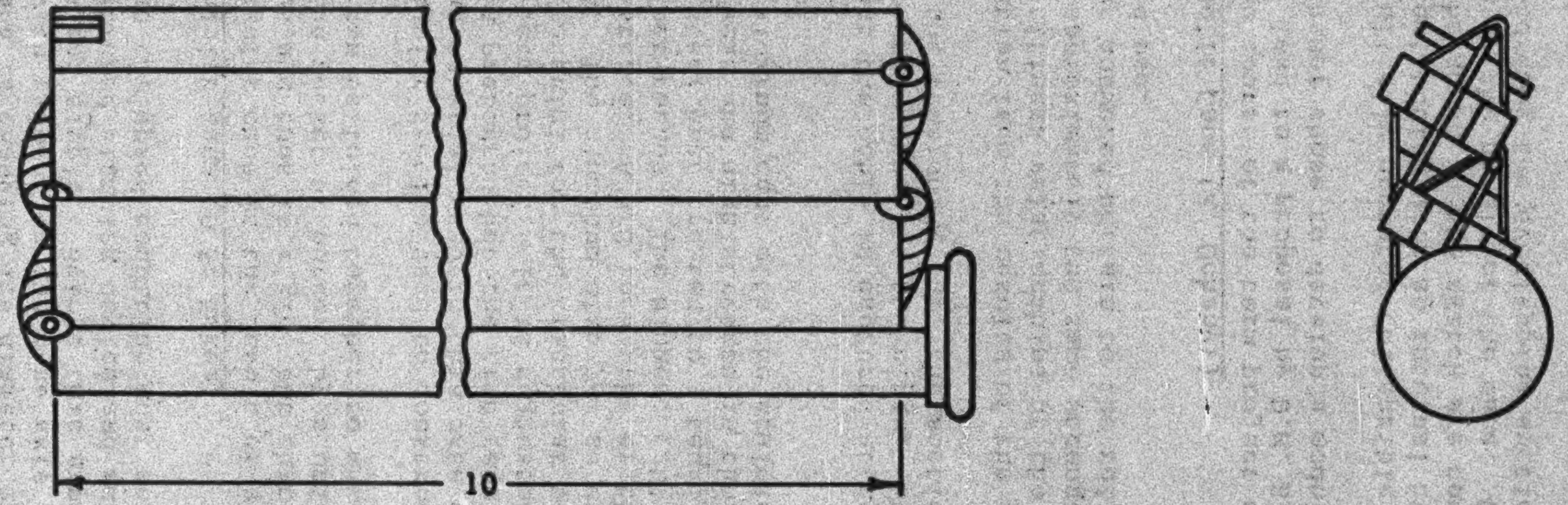
Extrapolation from the results of the SAE 1010 cane and from calculations of the strength and stiffness relationships of the proposed model, it appears that a triangular cane can have approximately the same strengths as the present long cane. Other questions to be answered pertain to the reliability and life of the hinges and cable under prolonged use.

The Hydraulic Cane (R. Ochsner)

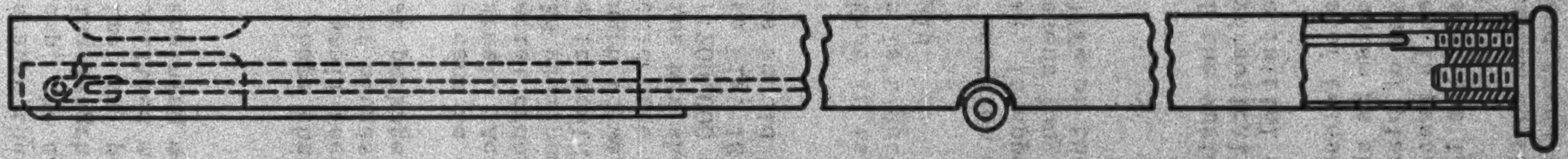
During the course of the term project discussions of the various methods of fixing the joints lead to a proposal by D.M. Baumann of a hydraulically pressurized joint. Mr. Ochsner chose to develop a model based on the initial suggestions.

The hydraulically operated collapsible cane consists of telescoping cylindrical sections of steel tubing with an internal hydraulic mechanism as shown in Fig. 19. The rubber bulbs shown in the sketch are connected by means of plastic tubing to a pump mechanism in the handle of the cane. When the system is pressurized, the rubber bulbs expand, forcing the overlapping sections together and thus locking the joints.

To facilitate the contraction of the hydraulic mechanism to the collapsed length of the cane, the plastic tubing was wound into a spiral and annealed so that its final shape resembled that of a telephone cord. The steps in this operation are as follows. A piece of flexible wire is first inserted in the 1/8 inch Tygon tubing. The tubing is then wound around a 1/8 inch metal rod and secured in this position. The assemblage is placed in boiling water for 15 or 20 minutes, and after this heat treatment the tubing will retain a spiral shape without support.



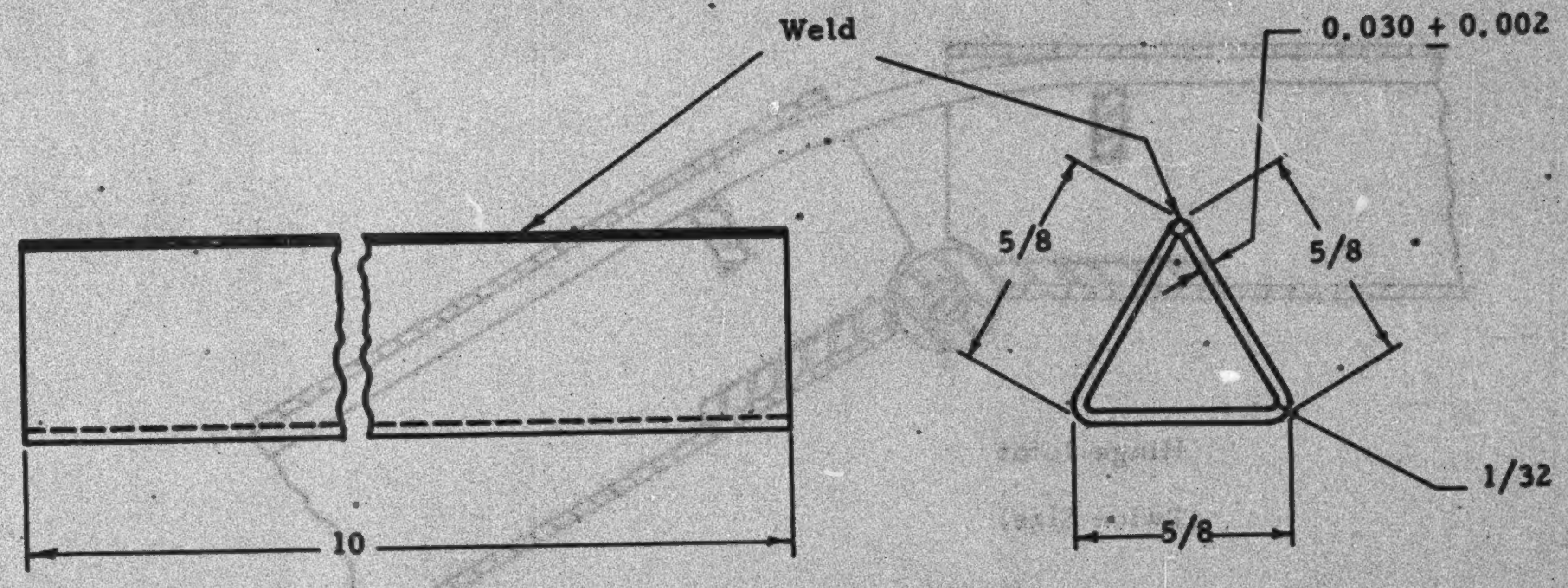
Folded



Extended - Triangular-hinge Cane - Full Scale

Fig. 16. Triangular-Hinge Cane.

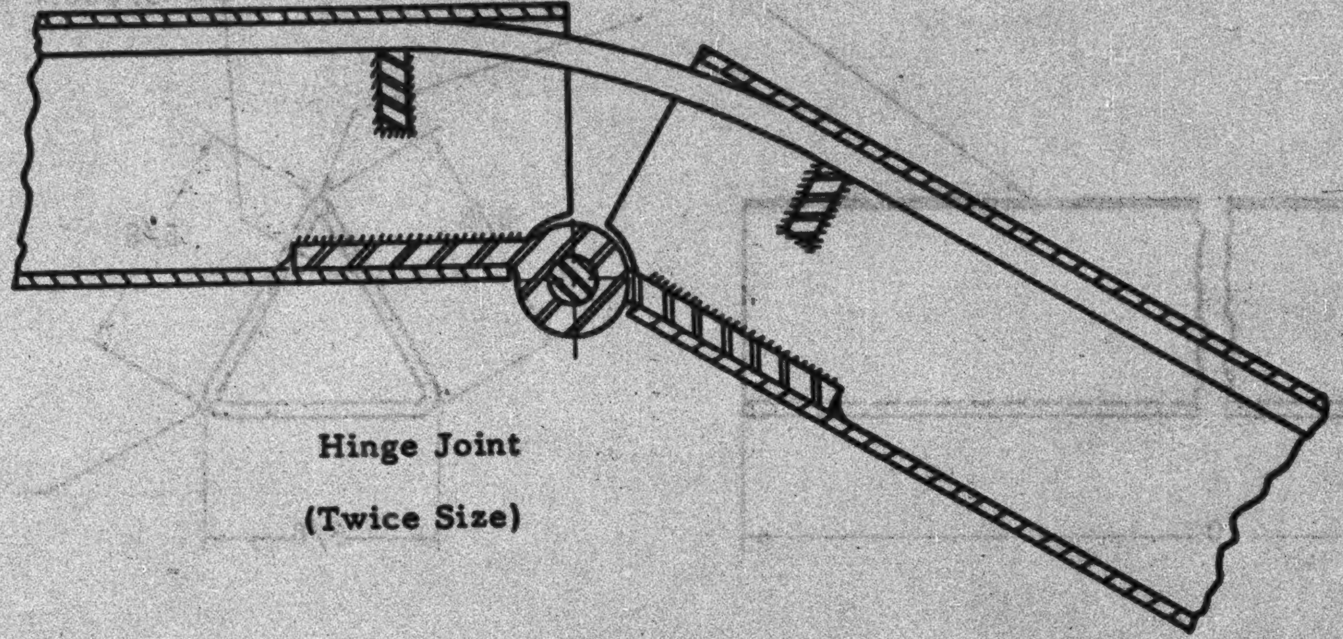
SAE 1010 Sheet Steel


Weld
0.030 ± 0.002
5/8
5/8
5/8
1/32
10

All dimensions ± 1/32

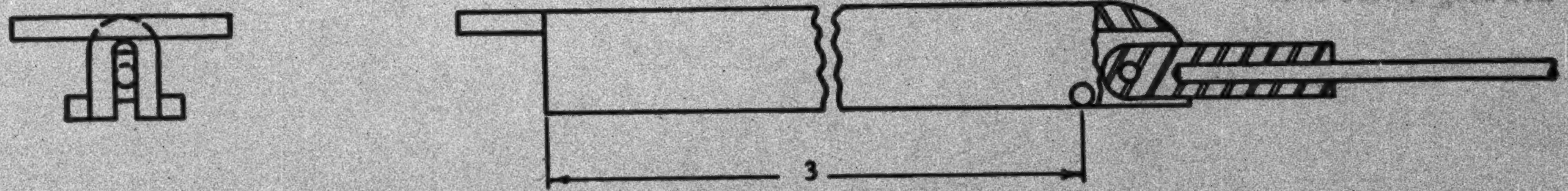
Drawing Twice Size

Fig. 17. Triangular Cane Section.



Hinge Joint

(Twice Size)



Locking Lever (Twice Size)

Fig. 18. Hinged Cane Details.

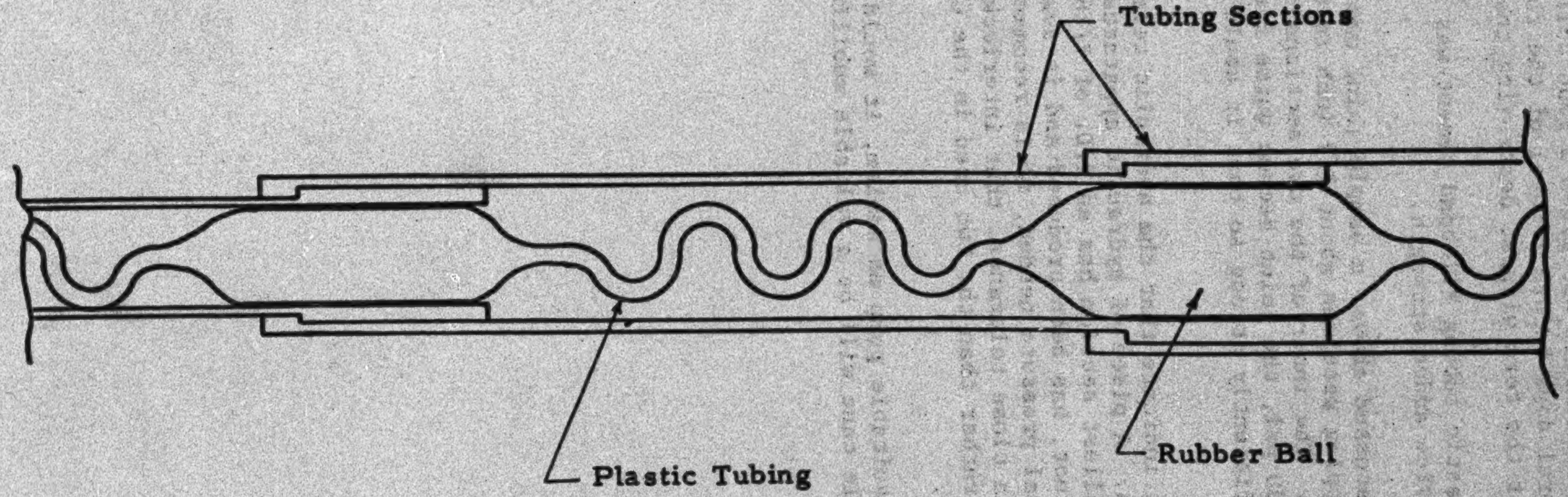

Tubing Sections
Plastic Tubing
Rubber Ball

Fig. 19. The Hydraulic Cane.

The rubber bulbs were made by coating a form with air curing latex and subsequent removal of the form. Ten or twelve coats administered at intervals of not less than half an hour proved to be adequate. The forms were made of Wood's metal and were cast in moulds of plaster of Paris, after which they were machined to their final shape. Wood's metal melts at 60°C., and originally the forms were removed simply by melting them out. However, it was found that if the mould was given a good polish, and if the rubber was allowed to cure for several days before removal of the form, the bulbs could with some difficulty be peeled off the form without destroying the latter.

To bond the rubber bulbs to the plastic tubing Pliobond cement was used. The joint was then coated with Epoxi to provide added strength.

To test the ideas and materials discussed above, a sample joint was produced and tested. It consisted of two overlapping sections about 1/2 inch in diameter surrounding a rubber bulb 2 inches long. The inner of the two sections had two slits cut in it. At an internal pressure of 30 psi, the joint became quite firm, with no apparent slop, and by 40 psi it was sufficiently strong so that it could not be pulled apart by the experimenter.

The results of the above experiment indicate that the hydraulic telescoping cane is a practical and promising design. A piece of hydraulic apparatus suitable for use in a five section cane whose smallest section has an I.D. of 7/16 inch, the length of each section being about one foot, has been produced and is available for further testing. To minimize the internal pressure needed, it is recommended that the overlapping sections be machined to a close tolerance, that interlocking grooves be machined in them and that four slits rather than the two used in the experimental joint should be cut in the inner section.

Contingent on the development of a suitable pump mechanism, it would appear that the hydraulic telescoping collapsible cane will be a valuable mobility aid for the blind.

II

VIBRATION ANALYSIS OF THE CANE

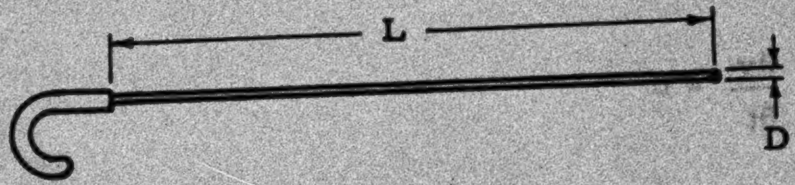
by

T.L. DeFazio and T.B. Sheridan

EDITOR'S NOTE:

This paper was based on the "Evaluation Report on Work in Progress on Sensory Aids and Prosthetics," Report No. 8768-3, Department of Mechanical Engineering, Massachusetts Institute of Technology, October 31, 1962. The following work was sponsored by the Department of Health, Education and Welfare, Office of Vocational Rehabilitation (contract SAV-1004-61). Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

The following is a vibrational analysis of a standard aluminum cane provided by the American Foundation for the Blind. The analysis is not completed because the evaluation of the expressions obtained becomes impracticable in the present context. Obviously then application of the numerical data is not possible. The analysis is presented rather as an example or approach to how one would consider a cane according to classical vibration theory.



The cane consists of a length of aluminum tubing about 50 inches long, with a light tip and a curved handle of heavier tubing.

L/D is about 100, so that any shear deflections would be small compared to flexure deflections.

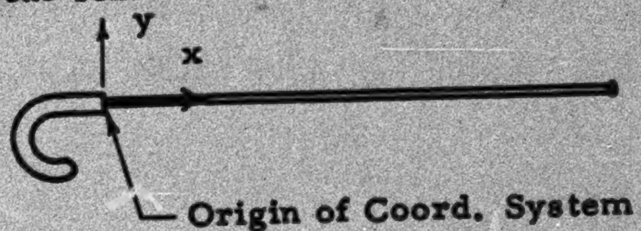
Compression waves are possible, but the fundamental natural frequency for compression waves is about 12,000 per sec. or about 2Kcps. (This fundamental is given by

$$\frac{\pi}{L} \frac{\sqrt{E}}{p} ; \quad E \text{ - Young's modulus, } p \text{ - mass/volume)}$$

This frequency is presumably above human threshold, so the cane may be considered a rigid body in compression so far as the human operator is concerned, but not necessarily as far as instrumentation is concerned.

Neglecting other than the flexure modes, the behavior between the ends of the cane is described by:

$$\frac{\partial^2 y}{\partial t^2} = \frac{EI}{\rho} \frac{\partial^2 y}{\partial x^4}$$



E - Young s modulus

I - Area moment of inertia

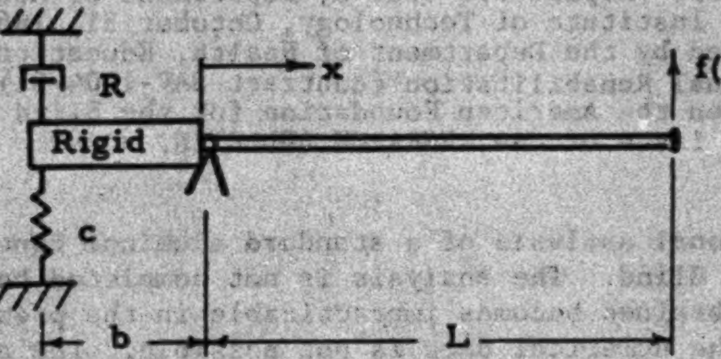
p = mass/length

t - time

Appropriate right-end conditions are:

$$y = f(t) \qquad \frac{\partial^2 y}{\partial x^2} = 0$$

Several sets of left-end conditions may be considered. The first is a result of considering damping and compliance as a representation of a hand, thus:



such that $y = 0$ **and** $EI\ \partial^2 y/\partial x^2 + (R\ \partial/\partial t + 1/c)(b\ \ \partial y/\partial x) = 0$

but

$$y = \frac{\partial y}{\partial t} = 0$$

so

$$EI\ \frac{\partial y}{\partial x}\ + g(t) + c = 0 \qquad\qquad g,\ c,\ \text{arbitrary}$$

Natural frequencies and frequency response can be evaluated by assuming $f(t) = \alpha \sin\omega t$ **and**

$$y = \Upsilon(t)\ \Upsilon(x)$$

for

$$x = \sqrt{\frac{B}{\omega}}, \quad \lambda_n = \sqrt{\frac{B}{\omega_n}}\ , \quad B = \sqrt{\frac{EI}{\rho}}\ ,$$

letting,

$$\Upsilon(x) = c_1 \sin \frac{x}{\lambda} + c_2\ \text{sinch}\ \frac{x}{\lambda} + c_3 \cos \frac{x}{\lambda} + c_4 \cosh \frac{x}{\lambda}$$

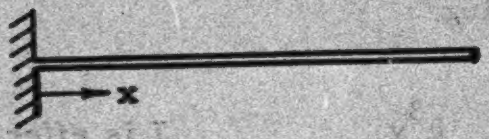
We get $c_3 + c_4 = 0$ from the right end, and from the left end we get:

$$\begin{bmatrix} \sin \frac{L}{\lambda} & \sinh \frac{L}{\lambda} & \left(\cos \frac{L}{\lambda} - \cosh \frac{L}{\lambda}\right) \\ -\sin \frac{L}{\lambda} & \sinh \frac{L}{\lambda} & -\left(\cos \frac{L}{\lambda} + \cosh \frac{L}{\lambda}\right) \\ 2 & 2 & -2p \end{bmatrix} 0 \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} a \\ 0 \\ 0 \end{bmatrix}$$

$$p = \frac{\omega}{b} \text{ EI } \sin \omega t; \quad 2 = \sqrt{\omega b}\left(R\, \omega \cos \omega t + \frac{\sin \omega t}{c}\right)$$

Inversion is difficult.

The second assumes a fixed left end, implying that the cane is held very tightly:



Thus

$$y = \frac{\partial y}{\partial x} = 0$$

Solution is given in Engineering Vibrations, Jacobsen and Ayre, p. 496. The form is again $y = \sum_{n-1} \Upsilon(t)\, \Upsilon_n(x)$ with $\Upsilon(t) = a \sin \omega t$ and

$$\Upsilon_n(x) = B_n\left(\cos \frac{x}{\lambda_n} - \cosh \frac{x}{\lambda_n}\right) + D_n\left(\sin \frac{x}{\lambda_n} - \sinh \frac{x}{\lambda_n}\right)$$

where

$$\frac{B_n}{D_n} = \frac{\cos \frac{L}{\lambda_n} + \cosh \frac{L}{\lambda_n}}{\sin \frac{L}{\lambda_n} - \sinh \frac{L}{\lambda_n}}$$

$\frac{L^2}{\lambda_n{}^2}$ is given by $\cos \frac{L}{\lambda} \cosh \frac{L}{\lambda} = -1$

for n = 1, 2, 3, 4, we have:

n	1	2	3	4
$\frac{L^2}{\lambda_n^2}$	3.52	22.1	61.8	121

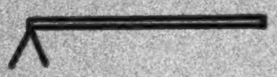
$\omega_1 \approx$ 40/sec. or 6.4 cps, by experiments on a specific cane, so for n = 1, 2, 3, 4,

n	1	2	3	4
ω_n, sec.$^{-1}$	40	266	743	1450

A third set of left-end conditions approximates a cane tightly held between two fingers, that is, free to pivot, but neglects the mass of the cane handle. (The cane handle may be accounted for by letting

$$y = 0 \qquad \frac{\partial^2 y}{\partial x^2} = \frac{J}{EI}\,\frac{\partial^3 y}{\partial t^2 dx} \quad \text{at } x = 0$$

J is effective mass moment of inertia of handle about origin of coordinates



Thus

$$y = 0, \qquad \frac{\partial^2 y}{2x^2} = 0$$

and the following Jacobsen and Ayre, p. 494,

$$C_n = \frac{\cos\frac{L}{\lambda_n} + \cosh\frac{L}{\lambda_n}}{\cosh\frac{L}{\lambda_n} - \cos\frac{L}{\lambda_n}}$$

and

$$Y_n(x) = \left[C_n + 1\right] \sin\frac{x}{\lambda_n} + \left[C_n - 1\right] \sinh\frac{x}{\lambda_n}$$

where

$$\lambda_n^{\,2} \text{ given by } \tan L/\lambda_n = \tanh L/\lambda_n$$

n	1	2	3	4
$\frac{L^2}{\lambda_n^{\,2}}$	0	15.4	50	1042

or for the specific cane

n	1	2	3	4
ω_n, sec^{-1}	0	175	568	11900

Considering no support and a weightless handle, (handle weight can be accounted for by letting, at x = 0,

$$\frac{\partial^2 y}{\partial x^2} = \frac{J}{EI}\,\frac{\partial^3 y}{\partial t^2 \partial x} \quad \text{and} \quad \frac{\partial^2 y}{\partial t^2} = \frac{EI}{n}\,\frac{\partial^3 y}{\partial x^3}\text{, } n = \text{handles mass)}$$

the solution (Jacobsen and Ayre, p. 493) is

$$C_n = \frac{\cos \frac{L}{\lambda_n} - \cosh \frac{L}{\lambda_n}}{\sin \frac{L}{\lambda_n} + \sinh \frac{L}{\lambda_n}}$$

$$Y_n(x) = C_n \left(\cos \frac{x}{\lambda_n} + \cosh \frac{x}{\lambda_n}\right) + \sin \frac{x}{\lambda_n} + \sinh \frac{x}{\lambda_n}$$

where

$$\lambda_n^{\,2} \text{ are given by } \cos \frac{L}{\lambda_n} \cosh \frac{L}{\lambda_n} = 1$$

n	1	2	3	4
$\frac{L^2}{\lambda^2}$	0	22.3	61.5	121

or for tubing of specific cane,

n	1	2	3	4
ω_n, sec.$^{-1}$	0	254	700	1375

Note that a model such as this implies that no information is transmitted to the user of the cane.

It is our opinion that a set of boundary conditions that accounts accurately for the hand of the user is necessary for any such calculations to be useful. Empirically, the damping due to the user's hand is "greater" than internal damping in the cane to such an extent that damping in the cane can likely be neglected if a good set of hand conditions is available. It is seen, however, that calculations quickly become difficult even for a linear model of a hand, as in our first example.

III

THE USEFUL DIMENSIONS OF SENSITIVITY[1]

by

James J. Gibson
Cornell University

EDITOR'S NOTE:

This paper was originally published in the AMERICAN PSYCHOLOGIST, Volume 18, No. 1, January 1963. Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

What I am going to talk about is the relation of sensing to perceiving. We have all believed that we understood the process of sensation fairly well and that only the process of perception gave us difficulties. But I am going to suggest on the contrary that a straightforward theory of perception is possible and that it is our understanding of sensation which is confused.

First let us make sure that there is really a problem in how to treat sensing and perceiving. Some psychologists now maintain that there is no difference between them in fact. The distinction has broken down; they say it has no validity and we should forget it. I think that what they mean is this. An individual can make discriminations in many ways. We can say either that he is sensitive to many variables of stimulation or that he can experience many kinds of differences between things but what has importance, the argument goes, are only the facts of discrimination, not whether they are called sensory or perceptual. There is something valid in this argument. I would call it the experimentalist's position--stick to the facts and cut the cackle! It is enough to determine just what differences an animal, a child, or a man can respond to and what others he cannot. This limited aim of psychology might be called simple psychophysics (not metric psychophysics) and it is good experimental science. But it provides no explanation of how the individual keeps in touch with the environment around him. The problem of perception, then, the problem of contact with the environment, still remains.

The variables of sensory discrimination are radically different from the variables of perceptual discrimination. The former are said to be dimensions like quality, intensity, extensity, and duration, dimensions of hue, brightness, and saturation of pitch, loudness, and timbre, of pressure, warm, cold, and pain. The latter are dimensions of the environment, the variables of events and those of surfaces, places, objects, of other animals, and even of symbols. Perception involves meaning; sensation does not. To see a patch of color is not to see an object. To see the extensity of a color is not to see the size of an object, nor is seeing the form of a color the same as seeing the shape of an object. To see a darker patch is not to see a shadow on a surface. To see the magnification of a form in the field is not to see an approaching object, and to see the expansion of the whole field is not to observe one's own forward locomotion. To have a salty taste is not to taste salt, and to have a certain olfactory impression is not to smell, say, a mint julep. To feel an impression on the

---

[1] This work was supported in part by the Office of Naval Research under Contract 401 (14) with Cornell University.

skin is not to feel an object, nor is having sensations of strain and pressure to feel the weight of an object. To feel a local pain is not to feel the pricking of a needle. To feel warmth of one's skin, is not to feel the sun on one's skin, and to feel cold is not to feel the coldness of the weather. To hear sound is not the same thing as to hear an event, nor is to hear an increasing loudness to hear the approach of a sounding object. Finally, let us note that having a difference of sound sensation in the two ears is by no means the same as to hear the direction of a sound. The last case is instructive, for we do not in fact have such binaural differences in sensory experience but we do localize sounds.

Having sensations is not perceiving, and this fact cannot be glossed over. Nevertheless, perceiving unquestionably depends on sensing in some meaning of that term. That is, it depends on sensitivity or the use of the sense organs. To observe, one must sense. The question I wish to raise is whether or not it is true that to observe one must have sensations.

I realize that any inquiry into the relation of sensing to perceiving raises the ghosts of formidable men. It is disconcerting to feel that Locke, Berkeley, and Hume are looking over one's shoulder, or that Kant and two generations of Mills are raising their eyebrows. A perceptual theorist can get into staggering muddles, and he does well to be cautious. Nevertheless, I have a set of hypotheses to propose and you may judge it both for internal contradictions and for conformity with the facts. My first suggestion, the general thesis, is that the useful dimensions of sensitivity are those that specify the environment and the observer's relation to the environment. There are other dimensions of sensitivity which do not specify such facts and relations, but they are not useful in this way, being only incidental to the activity of perception.

A whole set of correlative hypotheses go along with this radical thesis. They need to be understood before it begins to have plausibility, and the theory should be considered as a whole. The facts of sensory psychology and sense physiology are so varied and voluminous that it is not easy to stand back and take a fresh look at the evidence. Moreover, each of us is apt to have his own private opinion about the data of his senses. But if you will suspend belief in the standard doctrine of sensation and question your favorite introspections, I hope to convince you that the explanation of sense perception is not as difficult and roundabout as it has always appeared to be.

Consider first the puzzle of perceptual constancy. I will not attempt to review the experiments measuring the tendency toward constancy which are limited to vision and which, in any case, are indecisive. Instead I will point to the general evidence for an invariance of perception with varying sensations. This invariance appears not only in vision but also in other senses, notably those excited by mechanical energy, hearing, and touch. The paradox of constancy--the "distal focusing of perception" as Egon Brunswik (1956) put it, is more than a matter of color, size, and shape constancy; it is the heart of the problem of useful sensitivity.

Figure 1 is a picture of a patchwork of visual sensations. Note that it is a cross section of a wide-angle cone of light rays which might enter a human eye, the left eye in this case. Figure 2 is a longitudinal section of such a wide-range cone. It is stationary and momentary as represented in the picture, but whenever the eye moves to a new fixation point it will take in a new cone of rays. At that station point in the room there exists a complete optic array of available stimulation, the array being sampled and explored by new fixations. Figure 3 shows that if the man moves, instead of his eye moving, the pattern of the entering array is transformed, that is, every patch of color in the array changes form, and the patchwork as a whole is altered.

All this is simply the outcome of the laws of ambient light, or what may be called optical perspective (Gibson, 1961). The laws of pictorial perspective with which we are more familiar are a special case involving the sheaf of rays at a picture plane

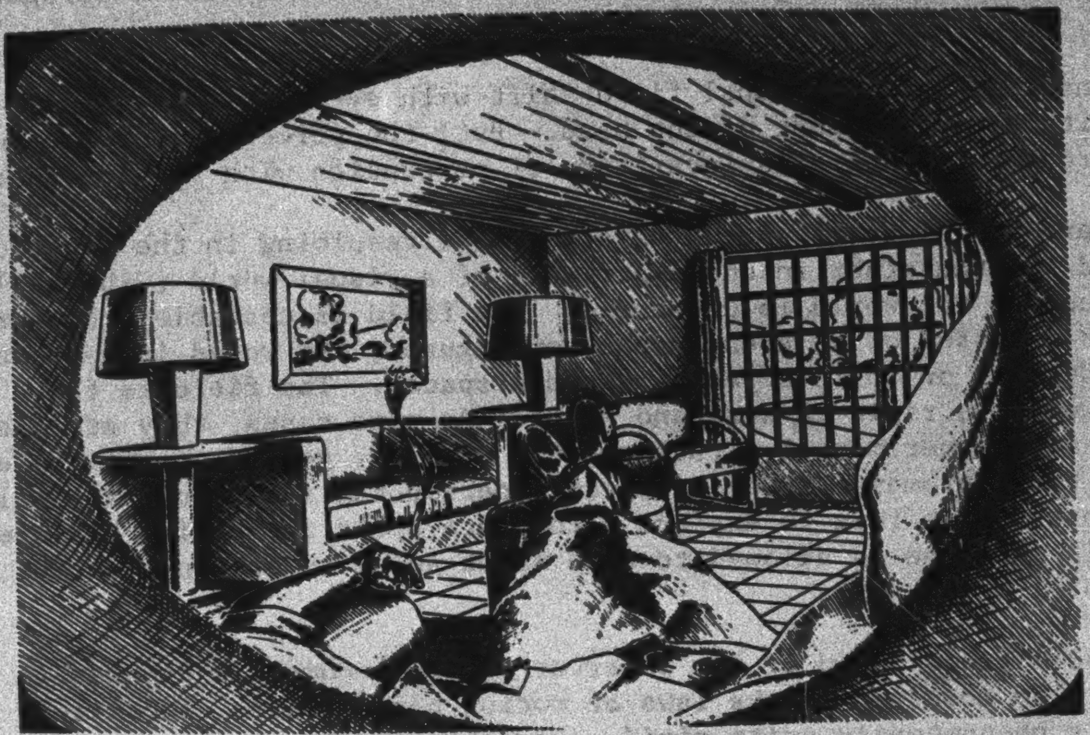


Fig. 1. Momentary cross section of the light entering a human eye.

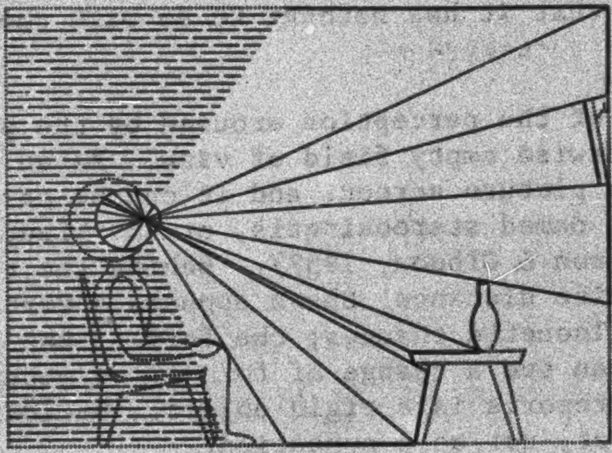


Fig. 2. Longitudinal section of the effective sector of an optic array.

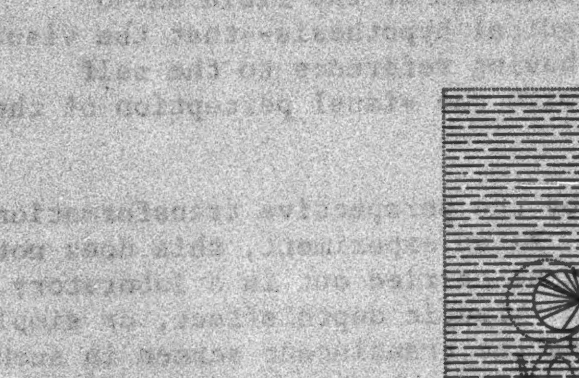


Fig. 3. Perspective transformation of the patchwork of an optic array due to change of viewpoint.

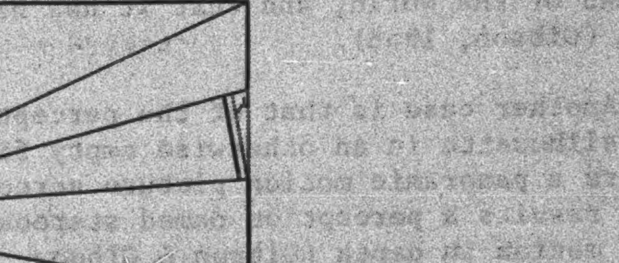


Fig. 4. The special case of a ray sheaf at a hypothetical picture plane.

(Gibson, 1960b). Figure 4 is an illustration of so-called linear perspective on a picture.

The sensations of the visual field shift with every movement of the eye, and transform with every movement of the head. But, the perception of the room remains constant throughout. There is invariance of perception with varying sensations.

There are two kinds of seeing, I argue, one resulting in the experience of a visual field and the other in the experience of a visual world (Gibson, 1950). The field is bounded; the world is unbounded. The field is unstable; the world is stable. The field is composed of adjacent areas, or figures; the world is composed of surfaces, edges, and depths, or solid objects and interspaces. The field is fluid in size and shape; the world is rigid in size and shape. As pure cases, they are distinct, although in many experimental situations the observer gets a compromise experience between the two extremes. However, these experimental situations are seldom ones in which the observer is free to explore a complete optic array with his eyes, and are never ones in which he is allowed to move about so as to obtain a series or family of perspectives.

The visual field ahead of the observer during locomotion expands in a sort of centrifugal flow governed by the laws of motion perspective. The visual world during locomotion is phenomenally quite rigid. Sensation varies but perception is invariant. To be sure, the observer sees his locomotion. The expansion of the field ahead specifies locomotion. This suggests a strange and radical hypothesis--that the visual sensation in this case is a symptom of kinesthesis, having reference to the self instead of the world, and that it has nothing to do with the visual perception of the world (Gibson, 1958).

Another case is that of the perception aroused by the perspective transformation of a silhouette in an otherwise empty field of view. As an experiment, this does not require a panoramic motion picture screen, and it can be carried out in a laboratory. There results a perception named stereokinesis, or the kinetic depth effect, or simply rigid motion in depth (Gibson & Gibson, 1957). Behind the translucent screen in such experiments, at an indefinite distance, there appears a virtual object moving in space. The form of the silhouette changes; the form of the phenomenal object remains invariant. The observer can see a change of form if he attends to the flat screen, but what he spontaneously reports is a rigid object. Ordinarily the transformation is seen as motion of the object, not as a sensation.

Another example is the familiar one that the color of the surfaces of the environment, including the white to black series, do not change as the illumination goes from brillant to dim. The corresponding sensations, however, the film colors obtained by seeing a surface through an aperture, vary widely with illumination. The perception of whiteness is quite a different matter from the sensation of brightness. With the available stimulus of a complete optic array, the ambient light reflected from a whole layout of surfaces, one can detect the actual physical reflectance of each surface. The absolute luminous intensity of a color patch determines the sensation of brightness, but only if it is taken in isolation.

Finally, I remind you of the difference between the binocular sensations of objects in depth and the binocular perception of the depth of objects. When one attends to his visual sensations one can notice the doubling or diplopia of images in the field of view; crossed diplopia from here to the fixated object, and uncrossed diplopia beyond that point. This doubling changes with every change in convergence, especially as we look to or away from what our hands are doing. We ought to see nothing as single except what lies on the momentary horopter. But of course we see everything as single, that is, we perceive it so. There is a phenomenal unity of each object despite an ever-varying doubleness of its sensation.

Auditory perception, we say, is based on a different mode or department of sense from visual perception. But the paradox of invariant perception with varying sensations holds nevertheless. Consider those very peculiar and special sounds, the phonemes of speech. They are acoustically analysable, it is true, in terms of intensity, frequency, and the frequency spectrum, but their distinctive nature consists of higher-order variables which are now beginning to be specified. Phonemes are the same at quite different levels of pitch and loudness, and hence are phenomenally constant for the voices of men, or women, or children. Speech cannot only be voiced; it can also be murmured, shouted, whispered, or sung. It can be emitted in falsetto, or even by a sort of whistling, without completely destroying the distinctive features which define the phonemic units of speech. They are invariant with changes of auditory sensation.

Consider also the hypothetical sensations that a hearer would get during auditory localization--the different sense impressions or sense data from the two ears. The main stimulus differences are ones of intensity and time of onset. As we know from the experiments of Wallach (1940) and others, the hearer turns and tilts his head from side to side, as if exploring, when he hears an unseen event. For a repeating sound, this means that the relative loudnesses and onsets of sensation are continually changing during the head turning. But the perception is that of a fixed or constant direction of the sound in space. As a matter of fact there is no evidence to show that any man or animal ever heard the changes of binaural sensations when turning his head. There is no awareness of such a flux. Binaural disparity never becomes conscious as binocular disparity can (Rosenzweig, 1961). I prefer to believe that the binaural mechanism is an active system which responds to disparity and tends to react by nullifying it, that is, by pointing the head toward the source of sound. The system responds to the sound field in the air, and we are misled when we consider only the wave train entering each ear separately.

So much for hearing. It is the sense of touch, so-called, that provides the clearest examples of the invariance of perception with varying sensations. In the last two or three years I have been running a series of experiments to test the limits of what an observer can do by touching or feeling without vision, that is, to discover what he can detect or discriminate about surfaces, edges, interspaces, objects, and motions in the neighborhood of his body. In these experiments we can compare the classical results obtained with passive punctate stimulation of the skin (intensity, locus, duality, and motion of a cutaneous impression or a pattern of such impressions) and the results obtained with the self-produced stimulation of touching. In general, an observer can perceive the properties of an object by active touch with quite surprising success. So also, of course, can a blind person. The following results come from a long series of observations (Gibson, 1962).

Rigidity. For example, when pressing on a rigid object with a finger, or squeezing it with the hand, there is an increase of sensation and then a decrease, or usually a flow of changing intensities. The perception, however, is of a constant rigidity of the surface. One simply feels the object. The impression on the skin as such is hard to detect. When one is touched by the same object instead of touching it, however, the variation of intensity is easy to detect. An observer can distinguish correctly between two protuberant surfaces, one rigid and the other yielding, when he presses them, but not when they are pressed on his passive skin.

Unity. When feeling one object between two fingers, only one object is felt, although two separated cutaneous sensations occur. This is a surprising fact when you consider it. The different local signs of these impressions have seemingly dropped out of the experience. The result is the same whether the object is held with two, three, four, or five fingers; the multiplicity of impressions on the skin has no effect on the perception of spatial unity of the object. It can be held by two hands and still be one object. It can be felt by many combinations of all 10 fingers, in rapidly changing combinations, and the perception of the object is all the better for it.

Stability. Active touch is exploratory and the observer tends to slide his finger over a corner or protuberance of a hidden object. The impression is then displaced over the skin and a feeling of tactile motion would be expected to occur. But the object is perceived to be stationary in space, and the tactile motion is not noticed. The perception is stable although the sensation is moving.

Weight. When one holds or lifts an object, the judgment of its weight is easier than when it is allowed simply to press downward against the skin of the supported resting hand. In active lifting, a whole set of additional inputs is involved. Besides the end organs of the skin and the deeper tissue, the receptors of the finger joints, wrist joints, and arm joints are excited, and the whole neuromuscular feedback system of the arm is activated. The flux and array of pressure sensations and articular sensations from a dozen or so joints ought to be of bewildering complexity. It probably would be if introspection could detect all that goes on in hefting a weight. But what the observer perceives is the mass of the object, unchanging despite the changing sensations. A weight comes to be as well or better perceived, in fact, when the object is shifted back and forth from one hand to the other. Something invariant emerges from this seeming mishmash of excitation. The perception is equivalent to that which accompanies the controlled and isolated sensory impressions of the standardized weight-lifting experiment.

Shape. A method of investigating the perception of unfamiliar shape by active touch is illustrated. Figure 5 shows an object behind a curtain with another identical (or different) object visible on a turntable. Figure 6 shows an observer feeling the object with both hands and judging whether the visible one is the same or different. Alternatively he might be required to match it with one of 10 visible objects, as shown in Figure 7. The degree to which these sculptured free forms differ among themselves is illustrated in Figure 8, where two are identical and the third different, and also in Figure 9, a view from the side. All these objects have six protuberances in front, and a rounded back. The ordinary observer, after very little practice, can distinguish among the tangible objects and match them to their visible replicas with little error (Caviness & Gibson, 1962).

FIG. 5. The visible object and the tangible object.

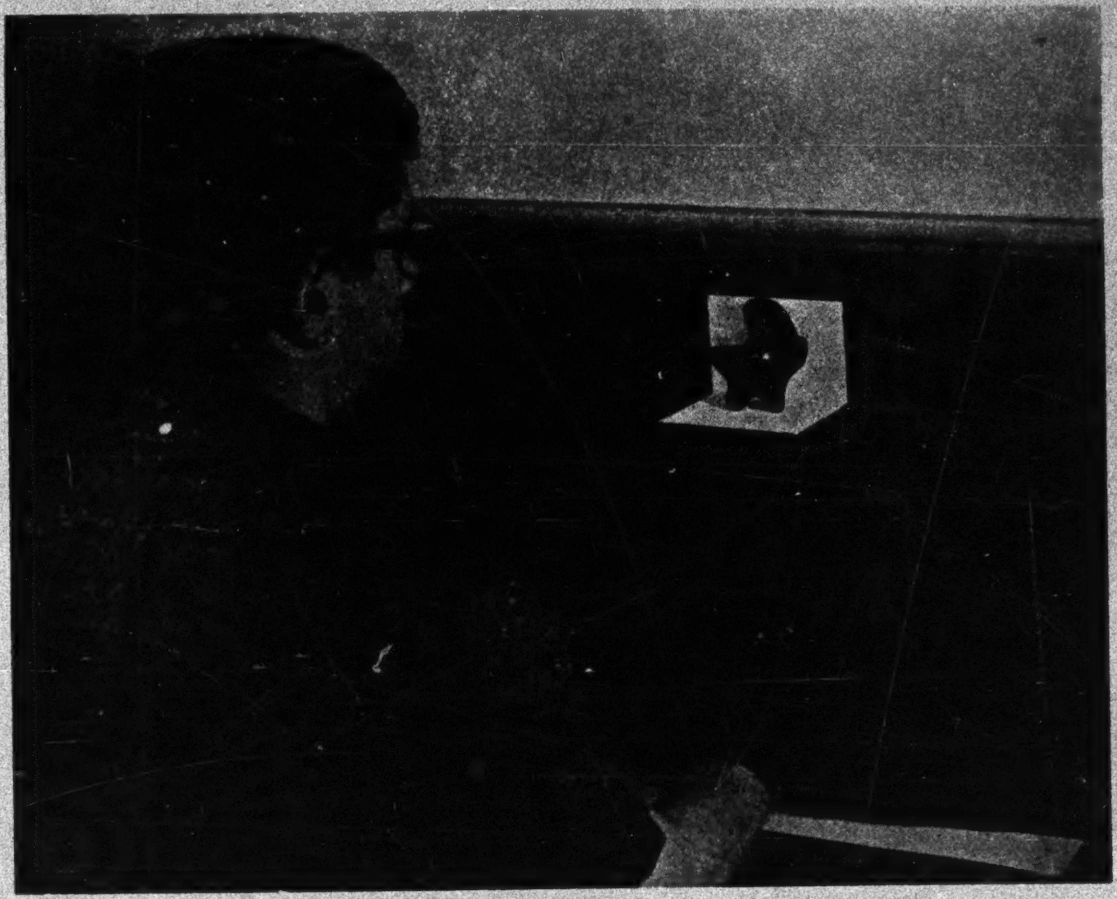


Fig. 6. An observer looking at one object and feeling another.

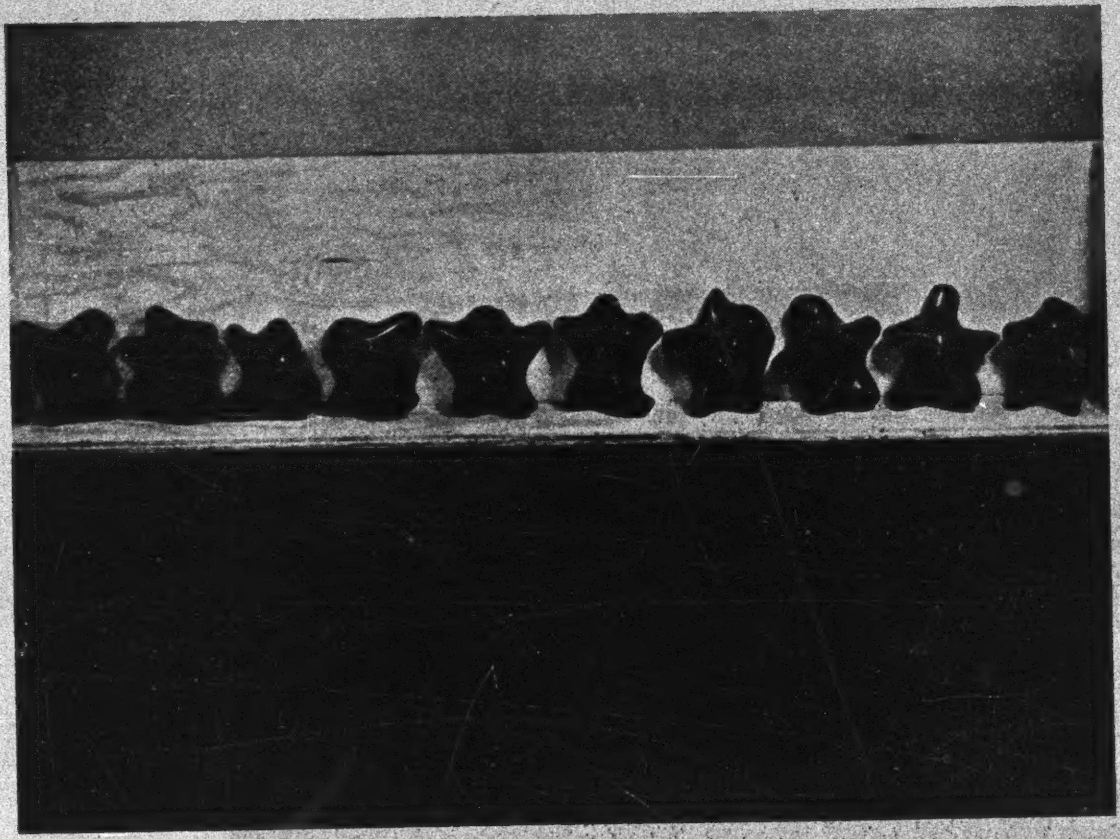


Fig. 7. The 10 sculptured objects used.

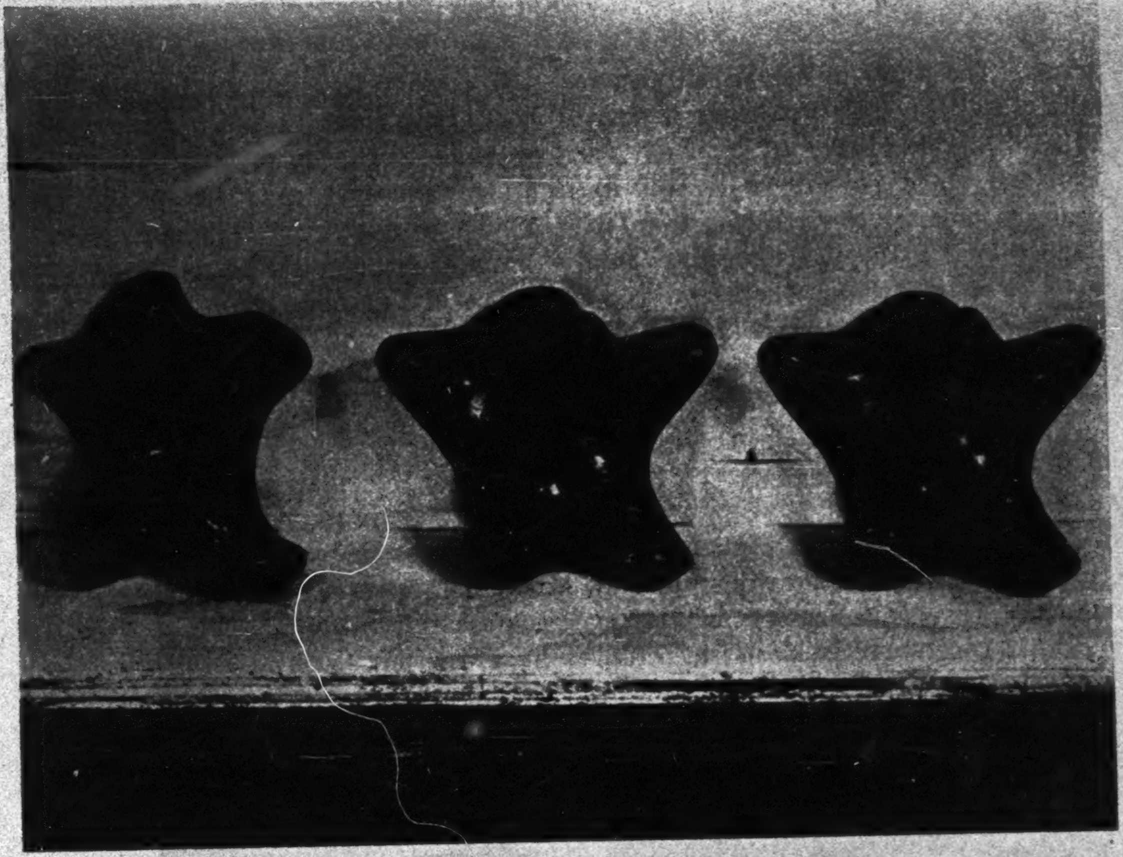


Fig. 8. Close-up of two identical and one different object.

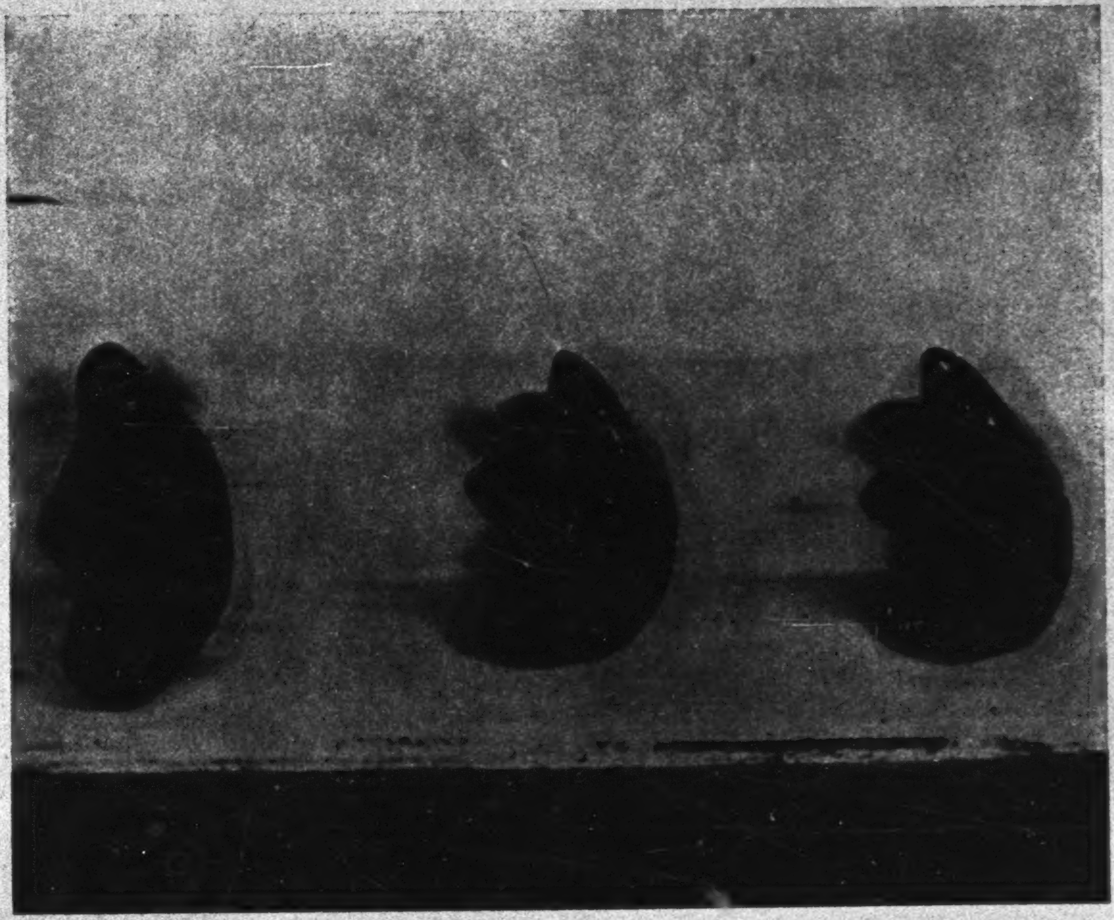


Fig. 9. Side view of three objects.

The haptic system of the exploring hand is sensitive to the variables of solid geometry, not those of plane geometry. It gets nothing of a flat picture, but it gets a great deal of the shape of a solid object. The hand can detect all of the following properties: the slant of a surface, the convexity or concavity of a surface, the edge or corner at the junction of two or more surfaces, and the separation of two edges, as our experiments demonstrate. Now it has always been assumed that the skin must be analogous to the retina--that it is a sensory mosaic which registers the form or pattern of the receptors excited. The skin and the retina can, in fact, do so when they are passively stimulated, and this has been taken to be their basic or sensory function.

If the cutaneous form sense is the basis for the feeling of objective shape, however, an impossible paradox arises. The series of cutaneous pressure patterns with a pair of exploring hands is something like that of a kaleidoscope; it seemingly has no rationale, and no single pattern is ever like the shape of the object. Nevertheless, from the inputs of the skin and the joints together, from the sensory system if not from the sensations, a remarkably clear perception of shape arises. The phenomenal shape of the object is invariant although the phenomenal patterns of sense data fluctuate and vary from moment to moment.

Conclusion. From all these facts of vision, hearing, and touch we ought to conclude that sensations are not the cause of perceptions. This is a strange statement. But I am willing to draw this conclusion. Conscious sensory impressions and sense data in general are incidental to perception, not essential to it. They are occasionally symptomatic of perception. But they are not even necessary symptoms inasmuch as perception may be "sensationless" (as for example in auditory localization). Having a perception does not entail the having of sensations.

The difficulty in accepting this conclusion is how to explain sense perception *unless* by way of sensations. But there is a way out of this difficulty, and that is to distinguish two meanings of the word "sense." Sensitivity is one thing, sensation is quite another.

The first meaning refers to the effects of stimulation in general. The second refers to conscious impressions induced by certain selected variables of stimulation. We can now assert that in the first meaning sensory *inputs* are prerequisite to perception, but that in the second meaning sensory *impressions* are *not* prerequisite to perception. In other words the *senses* are necessary for perception but *sensations* are not. In order to avoid confusion it might be better to call the senses by a new term such as *esthesic system*. We can then distinguish between sensory perception and sensory experience, between perception as a result of stimulation and sensation as a result of stimulation. The variables of stimulation that cause the first must be different from those that cause the second. Likewise the dimensions of sensitivity to informative stimuli must be different from those to uninformative stimuli.

How is the invariance of perception with varying sensations to be explained? By higher-order variables of stimulation which are themselves invariant, and by the sensitivity of esthesic systems to such invariant information. This kind of sensitivity is useful to animals. It may be innate, or acquired, or a little of both--that is a question for experiment. We can study it directly. We do not have to solve the puzzle of how there can be invariance of perception despite varying sensations. We do not have to inquire how sensations might be converted into perceptions, or corrected, or compensated for, or how one set of sensations might reciprocally interact with another set. If the sensations are disposed of, the paradox of perceptual constancy evaporates. Clearly the hypothesis of stimulus invariants is crucial for this explanation, and I will have to return to it later. Note that with this approach, a seemingly useful tool of experimenters, the index of constancy, loses its meaning. It ceases to be a measure of perceptual achievement. The supposed baseline of this ratio, the "retinal" size, shape, or brightness, cannot be used in a computation of the achievement if it is not the basis of the perception. It falls in a different realm of discourse, and it simply is not commensurable with perceptual size, shape, or brightness.

What are sensations? We might well pause at this stage to consider what is being discarded. Just what are these experiences that the perceptual theorist should no longer appeal to? I suggested at the beginning that our understanding of sensations has always been obscure. The reason for this, I think, is that the term sensation has been applied to quite different things. Let us examine the various meanings of the word to be found in philosophy, psychology, and physiology.

1. The theoretical concept. Theories of perception, as already noted, have always assumed that sensations were the necessary occasions of perception; that they were entailed in perceiving. This is precisely the assumption that is being challenged by my distinction between sensation and sensitivity. Its plausibility comes only from the evidence that stimuli are the necessary occasions of perception. I shall argue that none of the kinds of experience which have been called sensory requires this theoretical assumption.

2. The experimentalist's concept. In psychophysical experiments the variables of sensation have been taken to be correlates of the variables of physical energy which the experimenter could apply to his observer. In the past, the latter have tended to be those which were fundamental for physics proper, and which were controllable by borrowing the instruments of optics, acoustics, and mechanics. The favorite physical variables were intensity and frequency for wave energy, along with simple location or extension, and time or duration. But these dimensions of stimulation have little to do with the environment. They are fundamental for physics but not necessarily so for sense organs. The dimensions of available stimulation in a natural physical environment are of higher order than these, being variables of pattern and change. We are beginning to be able to control these natural stimulus variables. Note also that the stimuli of classical psychophysics are applied to a passive observer by an experimenter whereas the stimuli in perceptual psychophysics are obtained by an active observer (although the opportunities for obtainable stimulation are provided by the experimenter). The experiences resulting from these two situations are apt to be different, as the experiments on active touch demonstrate.

3. The physiological concept. The early physiologists discovered the receptor elements of the sense organs and assumed that these cells (rods, cones, hair cells, etc.) were the units of a receptor mosaic. Hence a sensation was taken to be a correlate of a single receptor, that is, the end organ of a nerve fiber. But we are now fairly sure, after recording from single fibers with microelectrodes, that the functional units of a sense organ are not the anatomical cells, but groupings of cells. It was also assumed, after Johannes Muller, that a specific mode or quality of sensation corresponded to any given nerve or fiber. But this generalization too can no longer be supported since, for one thing, the same fiber can participate in different groupings and have thereby different receptive functions. When Muller insisted that the mind had no direct contact with the environment but only with the "qualities of the sensory nerves," he was confusing sensitivity with sensation. He assumed that the function of the senses was to provide sensations. He was right, surely, to maintain that perception depends on stimulation but wrong to maintain that it depends on the conscious qualities of sense. A sense organ has to be defined as a hierarchy of functional groupings of cells, and they are not always adjacent anatomically.

4. The analytic concept. The attempt to reduce consciousness to its lowest terms by introspection culminated in Titchener. A sensation was taken to be an irreducible experience not analysable into components--a simple datum. It is fair to say that the attempt failed. Sensations as combining elements are no longer advocated, although the elegance and force of the structuralist program was such that traces of it are still influential in psychology. Conscious perceptions cannot always be reduced to

conscious sensations, as the Gestalt theorists have shown. It is clear that sensation in this meaning of the term is not prerequisite to perception.

5. The empiricist's concept. According to Locke and all the thinkers influenced by him, sense impressions are the original beginnings of perceptual experience prior to learning. They are innate, and pure sensations are had only by the new-born infant. They are without meaning and probably without reference to external objects. They are data for thought (or inference, or interpretation, or association, or other kinds of learning either automatic or rational). What they are like has been the subject of endless inquiry, and this explains our strong curiosity about the first visual experiences of the congenitally blind after the operation for cataract. The theory that original experience was composed of sensations has always appealed to psychologists because the available alternatives, nativism and rationalism, implied either a faculty of perception or a faculty of reason. But we can reject sensation as the original beginning of perception and accept useful sensitivity as something present from the start of life without being driven into the arms of faculty psychology. We can also avoid the nagging difficulty that infants and young animals (and the cataract patients, in my opinion) do not, on the evidence, seem to have the bare and meaningless sensations that classical empiricism says they should have.

6. The concept of an experience with subjective reference. There is still another possible meaning of the term sensation. It is the meaning used in saying that a stomach-ache is sensory rather than perceptual. The same could be said of an after-image as compared with an object, for it seems to refer more to the observer than it does to the outer world. In cases of passive tactual experience, the observer can feel either the impression on the skin as such or the object as such, depending on how he directs his attention. It is as if the phenomenal experience had both a subjective pole and an objective pole. Pain is ordinarily subjective (although there may be some objective reference, e.g., a pin) and vision is ordinarily objective (although there can be a subjective aspect, e.g., dazzle), but all senses, in this view of the matter, carry both subjective and objective information. The observer's body, as well as his environment, can always be noted, together with the relation between them. The body and the world are different sources of stimulation; there is propriosensitivity as well as exterosensitivity. Sherrington was wrong only in supposing that there are separate proprioceptors and exterocepters. All organs of sensitivity, I suggest, have this dual function.

Note that sensation considered as the subjective pole of experience is quite different from the other meanings of sensation. This is not the provider of data for perception or of messages or elements, nor is it the innate beginning of perception. This is a legitimate and useful meaning, but not the classical one--the basis of the experience of the external world.

Conclusion. Having examined the various kinds of experience that have been called sensory, I conclude that no one of them is required as the necessary occasion of perception. Several of them do undoubtedly occur in a man who introspects, or who serves as subject in an experiment, but the explanation of perception can dispense with all of them.

RECONSTRUCTION OF A THEORY OF PERCEPTION

If sensitivity is distinguished from sensation, and if perception depends on the former but not the latter, we will have to make a fresh start on the explanation of perception. We will have to discard many cherished doctrines and formulas (like separate and distinct modalities of sense), to clarify and find words for new things (like stimulus patterns and transformations), and to devise new experimental methods (such as how to control stimulus information instead of traditional stimuli). What are the requirements of a theory of perception not mediated by sense data?

Obviously it will have to show that sensitivity, with or without accompanying sensations, is adequate for all the manifold properties of perception (Gibson, 1959). It will have to show that the afferent inputs to the nervous system of a child or a man are rich enough to explain the degree to which he is aware of the world (but the inputs are taken to be those of active systems, not passive receptors or even sense organs). It will have to show that there is information in available stimulation (but the potential stimuli are taken to be limitless in variables of higher order). It will have to show that there are constants in the flow of available stimulation in order to explain constancy. It will have to show that these invariants in the ambient light, sound, and mechanical contact, do in fact specify the objects which are their sources--that something in the proximal stimulus is specific to the distal stimulus (Gibson, 1960a). It will have to suggest how these invariants can be discovered by the activity of selective attention (but there are hints of such a mechanism in what we already know about sense-organ adjustments, so-called, and about the selective filtering of higher nerve centers). It will have to explain propriosensitivity (self-perception) along with exterosensitivity (object perception), but without appealing to the oversimplified doctrine of a special sense of kinesthesis.

Moreover, the theory will have to explain all the observations and experiments of past generations which seem to make it perfectly evident that the observer contributes meaning to his experience, that he supplements the data, and that significance accrues to sensation. I have assumed limitless information in available stimulation from the natural environment. Therefore, the explanation must be that the experimenter has limited the available information in all such experiments, or else that, in a natural situation, the available stimulus information is impoverished, as by darkness or a disadvantageous point of view. Psychologists are accustomed to use stimulus situations with impoverished, ambiguous, or conflicting information. These have been devised in the hope of revealing the constructive process taken to characterize all perception. In these special situations there must indeed occur a special process. It could appropriately be called guessing. But I would distinguish perceiving from guessing, and suggest that we investigate the first and try to understand the second by means of corollaries about deficient information.

The theory will have to provide an explanation of illusions, not only the optical ones but those of all the other channels of sensitivity. The postulates of stimulus information and stimulus ecology, however, suggest ways in which the various illusions can be, for the first time, classified into types and subtypes of misperception, with the reasons therefore. A proper description of the information in an optic array will necessarily include a description of the information in a picture, and the ambiguous, conflicting, equivocal, or misleading information that can be incorporated in a picture. Note that illusions will be treated as special cases of perception, not as phenomena which might reveal the laws of the subjective process of perception.

Finally, the theory will have to be consistent with the known facts about social perception and all the information that has accumulated about the perception and learning of symbols and words. Here, you may think, a sensitivity theory of perception must surely fail. Even allowing that physiognomic and expressive character may have some basis in complex stimulation, words can have no meaning except that supplied by the perceiver. But this objection, cogent as it may sound, entirely misses the point. Once it is granted that stimuli may carry information, or have meaning, the whole theory of meaning is revolutionized, and we have to make a new start on it. Once it is granted that a child or a man can develop sensitivity to the invariants of the ecological stimulus environment it is no great step to admit that he can also learn to respond to the invariants of the social and the symbolic environments. The laws by which stimuli specify events and objects are not, of course, the rules or conventions by which chosen events or objects stand for others, but both are lawful. If animals and children can register perceptual meanings it is not surprising that children and adults can go on to register verbal meanings. However, just as the child does not first have a repertory of sensations and then attach meanings, so also he does not first hear a vocabulary of words and then attach meanings.

Role of Attention in Perception

An entirely different picture of the senses has emerged. For this to happen, we had to suppose that their sole function was not to yield sensations. Instead of mere receptors, that is receivers and transducers of energy, they appear to be systems for exploring, searching, and selecting ambient energy. The sense organs are all capable of motor adjustment. Figure 10 is a diagram which supplements and alters the usual stimulus-response diagram. It shows on the left the modification of stimulation by reactions of the exteroceptive system, and on the right the modification of reactions by stimulation of the proprioceptive system. The latter is familiar nowadays under the name of feedback, that is, the neural loops essential for the control of behavior. But the loops on the left are just as essential as those on the right. The organism has two kinds of feedback, not one. There are two kinds of action, in fact, one being exploratory action and the other performatory action. Muscles can enhance perception as well as do work and some, like the eye muscles, have this function exclusively. The hands, mouth and nose, ears, and eyes are all in their own way active systems, as the body is. The primary reaction to pressure on the skin is exploration with the fingers. Chemicals at the nose and mouth first elicit sniffing and savoring. Sound at the ears causes head turning. Light at the eyes brings about focusing, fixating, converging, and exploring of the light. Note that the outcome of all these adjustments is to obtain stimulation or, rather, to obtain the maximum information from the available stimulation.

This new picture of the senses includes attention as part of sensitivity, not as an act of the mind upon the deliverances of the senses. Every esthesic system is an attentional system. Attention is not an intervening process, therefore, but one that starts at the periphery. It also continues to select and filter the already selected inputs at nerve centers, as we know both from introspection and from the evidence obtained by microelectrode recording.

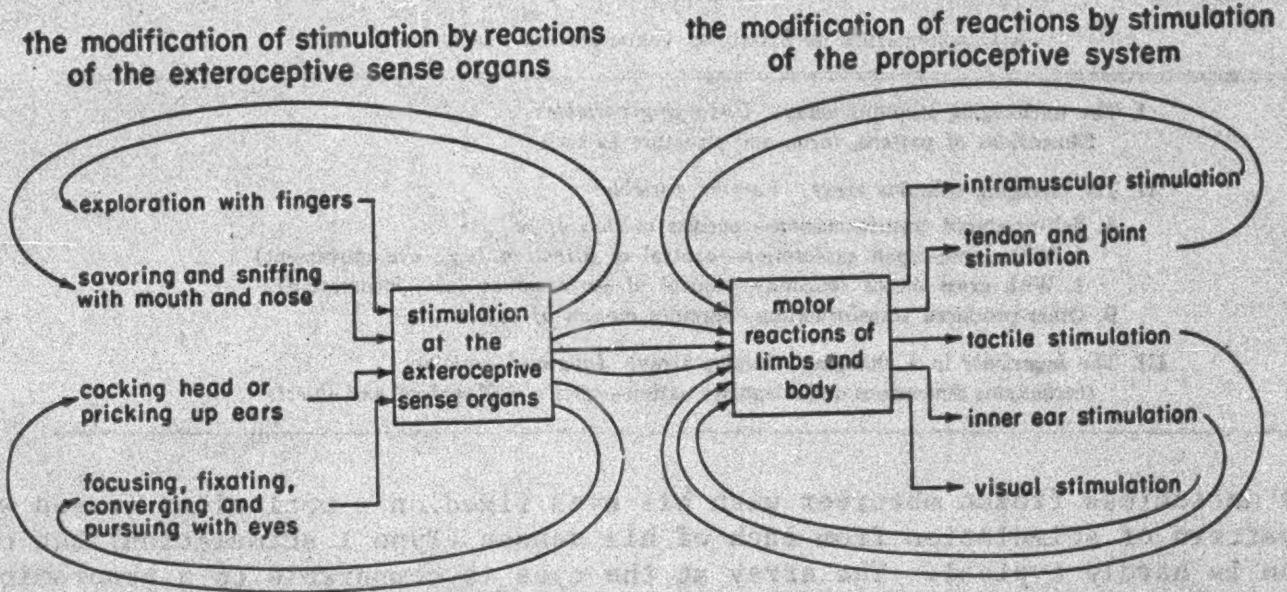

the modification of stimulation by reactions of the exteroceptive sense organs
the modification of reactions by stimulation of the proprioceptive system
exploration with fingers
savoring and sniffing with mouth and nose
cocking head or pricking up ears
focusing, fixating, converging and pursuing with eyes
stimulation at the exteroceptive sense organs
motor reactions of limbs and body
intramuscular stimulation
tendon and joint stimulation
tactile stimulation
inner ear stimulation
visual stimulation

Fig. 10. The feedback loops for exploring stimulation and those for controlling behavior. (The angular lines represent physical action; the curved lines represent neural action.)

Pattern and Change of Stimulation

Consider the sense organs in the old way, each as a population of receptive units. We have thought of the retina, the skin, the tongue, and perhaps the olfactory epithelium as examples of a sensory surface, a mosaic. Even the Organ of Corti and the lining of the statocysts may be conceived in this way. But note, parenthetically, that the flat surface analogy does not hold at all for the articular sense, that is, the set of receptors for all the joints of the skeleton. The point is that any population of receptive units is capable of delivering a simultaneous array of neural *inputs* (although it is gratuitous or false to call this a two-dimensional pattern or picture, as we do for the retina and are tempted to do for the skin). Apart from this muddle, every sense, then, is a pattern sense. Equally, they are all capable of delivering *a sequence or stream of neural inputs or changes in the simultaneous pattern*. Every sense is therefore a transformation sense as well as a pattern sense.

Consider next the stimulation for these senses, the *proximal* stimulation. In every case it also is a simultaneous array and a successive flux. There are two kinds of order in stimulation, as I once put it, adjacent order and sequential order (Gibson, 1950). Pattern and change are characteristic of stimulation in general, unless it has been sterilized by an experimenter, and here is where the information lies. For example, pattern and change occur at the retina and the skin--even more at the dual retina and the two-handed skin, as the experiments reported have shown. They occur at the basilar membrane of the cochlea as, respectively, the momentary sound spectrum and the transients of sound; moreover the binaural disparity patterns change with head movement. The simultaneous pattern of input from all joints of the skeleton taken together is a highly intricate and interlocked configuration, yet its slightest transformation seems to be registered when the individual moves. Pattern and change occur at the gustatory and olfactory surfaces, and even for the statocysts and the semicircular canals. Pattern and change are universal.

Now sensory physiologists have always recognized the importance of patterns of stimulation and tried to relate them to the sensory projection areas of the brain. What they have not understood is transformations of pattern. They have tried to imagine a cortical correlate of form, which is difficult enough (as witness Hebb's recent attempt to explain visual form perception, 1949), but not the changes of form which I have described. A tabulation may help to clarify the problem (Table 1).

TABLE 1

A CLASSIFICATION OF STIMULUS VARIABLES FOR PERCEPTION

I. The unchanging stimulus array. *Unvarying variables*
    Dimensions of pattern, form, and structure as such

II. The changing stimulus array. *Varying variables*
  A. Self-produced transformation—specifies *motion of self*
    1. With sense-organ exploration—control of *attention* (e.g., eye movement)
    2. With gross motor reactions—control of *performance* (e.g., locomotion)
  B. Other-produced transformation—specifies *motion of object*

III. The *invariants* in a changing stimulus array. *Invariant variables*
    Unchanging dimensions under transformation—specify *rigid surfaces and objects*

The motionless frozen observer with his eyes fixed on a motionless frozen world gets a pattern of stimulation from each of his senses (Type I stimulation) but the situation is hardly typical. The array at the eyes is comparable to a panoramic still picture. If he moves, or if something moves, the arrays change (at the eyes, the skin, and the joints, for instance) in specific ways or dimensions (Type II stimulation). I have worked out the dimensions of transformation for the eyes, and it ought to be possible to do this for the other systems. Subjective movement and objective motion (A and B) normally yield different stimuli even at the eyes. The observer can see himself moving, as one does in automobile driving, and even see his own eye movements, as in observing the shifting of an afterimage, but these are perceptions with subjective reference. They are "proprioceptive." We might say that the stimuli are propriospecific, since they carry information about the self.

The third type of stimulus variable is crucial since it is taken to explain the invariance of object perception. Change of an array usually involves nonchange. Some order is preserved in every transformation. Neither at the eye nor the skin nor at any other organ does the energy scintillate, as it were, like the random flashing of the fireflies in a field. There are always invariant variables alongside the varying variables. They are specific to (but not copies of) the permanent properties of external things. It is not a paradox that perception should correspond to the distal object, although it depends on the proximal stimulus, if the object is in fact specified in the stimulus. The Ames demonstrations purporting to show that optical stimulation can never specify objects depend on a frozen array from which the invariants cannot emerge.

Consider the difference between unvarying and invariant variables of stimulation (Type I and Type III). In the former case the stimuli that would be invariant do not get separated off from those that would vary if the array underwent transformation. The frozen array, the case of continuous nontransformation, carries less information. The case is one that never occurs in life. A prolonged freezing of the pattern of stimulation on the retina or the skin, in fact, yields an input which soon fades away to nothing.

The normal world is sufficiently full of motions and events to make a stream of stimulation. But even without external motions a flow is produced. The normal activity of perception is to explore the world. We thus alter its perspectives, if events do not alter them for us. What exploration does is to isolate the invariants. The sensory system can separate the permanence from the change only if there is change.

In vision, we strive to get new perspectives on an object in order to perceive it properly. I believe that something analogous to this is what happens in the active exploratory touching of an object. The momentary visual perspectives, of course, are pictures or forms in the geometrical sense of that term whereas the momentary tactual perspectives are not. Nevertheless they are similar since, for an object of a given solid shape, any change of cutaneous pattern like any change of retinal pattern is reversible. The impression of the object on the skin, like its impression on the retina, can recur by a reversal of the act that transformed it. The successive patterns thus fall into a family of patterns which is specific to the object. I submit to Hebb the suggestion that the first problem in perceptual physiology is not how the brain responds to form as such, unvarying form, but instead how it responds to the invariant variables of changing form. I think we should attempt a direct physiological theory of object perception without waiting for a successful theory of picture perception.

Invariant Properties of a Changing Stimulus Array

The crux of the theory of stimulation here proposed is the existence of certain types of permanence underlying change. These invariants are not, I think, produced by the acquiring of invariant responses to varying stimuli--they are in the stimuli at least potentially. They are facts of stimulus ecology, independent of the observer although dependent upon his exploratory isolation of them. This kind of order in stimulation is not created by the observer, either out of his past experience or by innate preknowledge. Just as the invariant properties of the physical world of objects are not constructed by the perceiver, so the invariant properties in available stimulation are not constructed by him. They are discoverable by the attentive adjustments of his sense organs and by the education of his attention.

Some of these stimulus invariants are extremely subtle. The ultimate subtleties of the information in stimulation may well be unlimited. But other invariants are quite simple and easily detected. The optical texture that specifies a physical surface (in contrast with the textureless patch that specifies an empty space) is invariant with illumination and under all transformations of perspective. Introspectively we say that one yields a surface color and the other a film color, but the spatial meaning is what counts, not the introspection. The textures of earth, air, and water are different, and the differences are constant. So are the differences that specify to the young of any species the fur, feathers, or face of the mother. The intensity and wave length of the light are irrelevant. The infant seems to be sensitive from the beginning, more or less, to such external stimuli as these. The tablet of his consciousness may be nearly blank at birth, as Locke believed, but the impressions that do appear are vague perceptions, not bare sensations. The earliest dimensions of sensitivity are useful ones.

Classical sense impressions, I think, are something of which only a human adult is aware. They tend to arise when he introspects, or when he tries to describe the content of experience, or the punctate momentary elements of perception, or when simple variables of physical energy are experimentally isolated for him by a psychologist, or when stimuli are applied to his receptors instead of his being allowed to obtain them for himself. Far from being original experiences, they are sophisticated ones; they depend on having had a great deal of past experience.

This is not to deny that perception alters with learning or depends upon learning. Instead it points to a different kind of learning from that we have previously conceived. Unquestionably the infant has to learn to perceive. That is why he explores with eyes, hands, mouth, and all of his organs, extending and refining his dimensions of sensitivity. He has to separate what comes from the world and what comes from himself. But he does not, I think, have to learn to convert sensations into perceptions.

REFERENCES

Brunswik, E. Perception and the representative design of experiments. Berkeley: Univer. California Press, 1956.

Caviness, J.A., & Gibson, J.J. The equivalence of visual and tactual stimulation for the perception of solid forms. Paper read at Eastern Psychological Association, Atlantic City, April 1962.

Gibson, J.J. The perception of the visual world. Boston: Houghton Mifflin, 1950.

Gibson, J.J. Visually controlled locomotion and visual orientation in animals. Brit. J. Psychol., 1958, 49, 182-194.

Gibson, J.J. Perception as a function of stimulation. In S. Koch (Ed.), Psychology: A study of a science. New York: McGraw-Hill, 1959. Pp. 457-501.

Gibson, J.J. The concept of the stimulus in psychology. Amer. Psychologist, 1960, 16, 694-703. (a)

Gibson, J.J. Pictures, perspective, and perception. Daedalus, 1960, 89, 216-227. (b)

Gibson, J.J. Ecological optics. Vision Res., 1961, 1, 253, 262.

Gibson, J.J. Observations on active touch. Psychol. Rev., 1962, 69, 477-491.

Gibson, J.J., & Gibson, E.J. Continuous perspective transformations and the perception of rigid motion. J. exp. Psychol., 1957, 54, 129-138.

Hebb, D.O. The organization of behavior. New York: Wiley, 1949.

Rosenzweig, M.R. Development of research on the physiological mechanisms of auditory localization. Psychol. Bull., 1961, 58, 376-389.

Wallach, H. The role of head movements and vestibular and visual cues in sound localization. J. exp. Psychol., 1940, 27, 339-368.

IV

USE OF AN OBSTACLE COURSE IN EVALUATING MOBILITY OF THE BLIND

by

J. Mickunas, Jr. and T.B. Sheridan

EDITOR'S NOTE:

This paper was based on the "Evaluation Report on Work in Progress on Sensory Aids and Prosthetics," Report No. 8768-3, Department of Mechanical Engineering, Massachusetts Institute of Technology, October 31, 1962. The following work was sponsored by the Department of Health, Education and Welfare, Office of Vocational Rehabilitation (contract SAV-1004-61). Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

General

The problem in this study was to design a representative obstacle course for the blind and to develop techniques to evaluate their behavior in traversing such an experimental obstacle course. Efforts were made to embody in the obstacle course the most salient features of the environment with respect to which the blind traveller interacts. In constructing such a course the following characteristics of the environment were considered: bounded and open spaces, type and distribution of the obstacle objects in the traveller's path, step-ups and step-downs, and auditory cues. The techniques of evaluation were objective and simple so that inexperienced observers could administer the necessary tests.

One group of five blind subjects traversed the obstacle course, under three environmental conditions, using Hoover's "long cane" technique. A second group of four naive, sighted-blindfolded subjects did the same. A third group of four naive, sighted-blindfolded subjects used two long canes. A fourth group of two naive, sighted-blindfolded subjects used a modified cane of "T" shape.

Each group traversed the course under three conditions of auditory cue availability starting with a quiet room, progressing to a background noise produced by ventilation fans, and going finally to a condition of complete auditory masking. Experimental measures were number of taps, total traverse time, and number of "harm events" observed in several categories.

Results of analysis of variance for taps and time suggest that both travel experience and cane configuration affect number of taps (and time, which is proportional to taps under all conditions). Moderate ambient noise does not increase taps required, but complete auditory masking does. Experienced blind travellers had fewer harm events as a group than the normally sighted, but differed considerably from one another.

The feasibility of an experimental course composed of artificial objects is demonstrated. An objective "success of travel" scale based on "harm events" is proposed.

Obstacle Course

The entire course was set up in a large, otherwise empty room, thus providing control over weather, interruptions by curious pedestrians, etc. The obstacle course modelled such characteristics of the environment as bounded paths, open streets, solid objects at ground level, objects protruding from above ground level, step-ups and step-downs, automobiles, sound reflectors, and stairways. Most of the obstacles and environmental features were of wooden construction. Their arrangement and purpose was to sample some characteristic features of the real environment. The diagram in Fig. 23 indicates positions of the obstacles in the course. The distance from the starting point to the finishing point was 170 feet. Figure 24 shows several views of the obstacle course.

Procedure

The subject reported to a room on the first floor. The experimenter put a blindfold over the subject's eyes and then led him to the third floor, where the obstacle course was set up. To reduce the subject's tension and give him some practice with the cane, he was instructed to walk a section of the room which was free of obstacles. The total distance of this free course consisted of two segments of 170 feet, the same total distance as the obstacle course. The time spent traversing this course was measured with a stop watch. The number of taps made by the subject with the cane was recorded on a portable tape recorder which the experimenter carried walking just behind and to the side of the subject. After traversing the free course, the subject was led to the starting point of the obstacle course. The following instructions were given to the subject to provide some mental image of the course:

> "This is the starting point of the obstacle course. To your right there is a brick wall. You have to walk straight until you reach a brick wall opposite you. Then, turn left and follow a confined path. To your right there will be a brick wall and to your left, two by fours placed on the cement floor. You have to stay within the confined path until you reach a wooden platform--we call it a sidewalk. You have to step up on to the sidewalk and walk to the end of it. At the end of the sidewalk you have to step down on to the street--it is the concrete floor. Keeping a straight line, you have to cross the street and find a second sidewalk--a wooden platform. You have to step on it and walk to the end--even though it turns sharply to the left at one point. Once you have reached the end of the second sidewalk, you have to step down on to a concrete floor. The path you have to follow is bounded by sheets of acoustic tile placed on the floor. Walking along this path, you will come to a stairway. Your task is to go up and go down the stairway. When you are on the concrete floor again, follow the bounded path until I ask you to stop. Any questions?"

If the subject asked questions, they were answered by the experimenter. Then the following resume was given to the subject:

> "As you have gathered, the course is roughly circular, in a sense that the finishing and starting points almost coincide. When you come up to an object, you will have to decide how to navigate further."

When the experimenter completed recording the date, subject's name, and the condition under which the course was to be traversed, he started the subject walking the course. For recording purposes the course was divided into eight segments. As the subject approached the end of a given segment, the experimenter identified it by recording on tape a coded number as well as the cumulative time up to that point. Likewise, an index of harm inflicted by the subject either upon himself or upon the environment was devised. These harm events were recorded as they occurred along the course. Three types of harm events were identified: bumping into an object, tripping upon an object, or getting the cane stuck. Bumping into an object was predicted upon significant body contact. Tripping was based upon the subject's momentarily losing his balance due to an unexpected collision of his feet with the environment. Through the entire experiment no subject was injured in any way as a consequence of tripping. Getting the cane stuck typically resulted whenever it got lodged between two objects or in the "cracks" of the sidewalks.

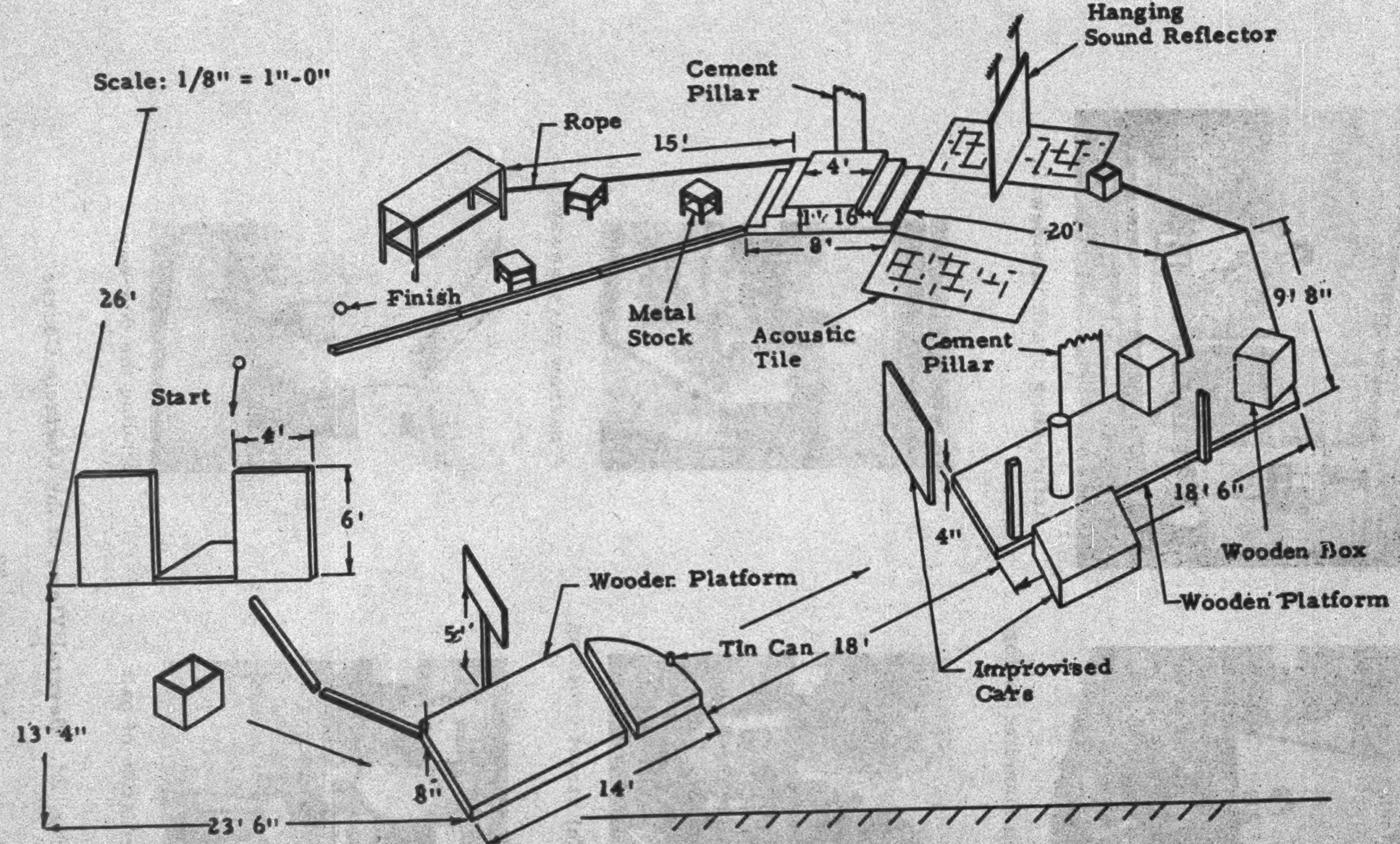

Scale: 1/8" = 1"-0"
26'
13' 4"
23' 6"
Start
4'
6'
Finish
Rope
15'
Cement Pillar
4'
1"/16"
8'
Metal Stock
Acoustic Tile
Hanging Sound Reflector
20'
9' 8"
Cement Pillar
4"
18' 6"
Wooden Box
Wooden Platform
Improvised Cars
Tin Can 18'
Wooder Platform
5'
8"
14'

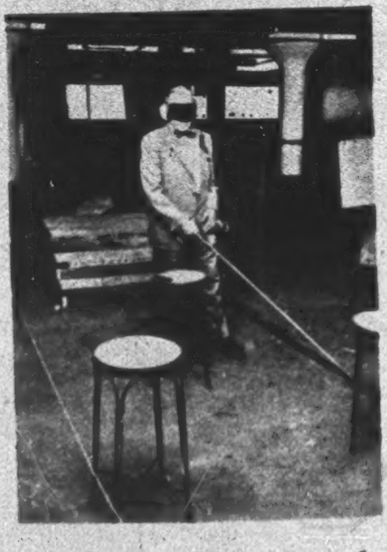
Fig. 23. Layout of Obstacle Course

Avoiding sound reflector

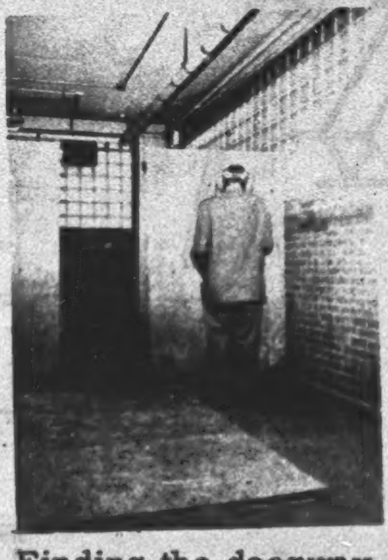
Anticipating crack in sidewalk

Successful street crossing

A narrow passageway



Confirmation of path



Finding the doorway

Fig. 24. Several Views of the Obstacle Course

The subjects traversed four times the course which was a quiet room free of obstacles. The length of a single segment of this course was 170 feet. The obstacle course was also 170 feet long. All subjects traversed the obstacle course three times under each of three different conditions. The first condition was a quiet room. Under the second condition two exhaust fans were turned on, providing background noise of about 60 db sound pressure level. For the last condition subjects wore Willson Sound Barrier earphones which damped external sound energy and provided 80-100 db white noise (from a modified transistor radio) which effectively masked out all residual auditory cues from the environment. The sighted subjects were not permitted to see the course until they had traversed it under all regular conditions. At the end the blindfolds were removed and the sighted subjects were asked to traverse the course still using the canes. Everything was tape recorded exactly in the same manner as under the previous conditions.

Three variations of canes and techniques were used to traverse the obstacle course. The first, used for most of the tests, was an ordinary aluminum "long cane" used in conjunction with the Hoover technique. The second variation consisted of two such aluminum canes--the second cane held in the normally free hand and manipulated in a mirror image of the first--resulting in a sort of crisscross pattern. The third variation consisted of a modified single cane, on which a 12-inch aluminum bar was attached perpendicularly on the tip of the aluminum cane, thus providing double contact points with the environment on the ends of the "T" bar. The subjects were instructed to use the latter with the Hoover technique also.

Subjects

Five blind subjects were from St. Paul's Rehabilitation Center in Newton, Mass. All were in their sixteenth week (their last) of training in the use of the cane. The sighted subjects were M.I.T. students. Because of retraining problems, each group of sighted subjects was used with only one cane condition. Four sighted subjects participated in the one cane condition, four in the two cane condition, and two in the "T" cane condition.

Results

Tape recorded data consist of cane taps, cumulative time (in seconds) and harm events while traversing both the free and obstacle courses. Table 5 shows the arithmetic means of cane taps, time (in seconds), and harm events for four groups of subjects under all investigated conditions and considering 170 feet segments of the free and obstacle courses. Tables 6, 7, 8, and 9 in the Appendix show the number of taps, time (in seconds), and frequency of harm events for each traversing of the courses. Table 10 in the Appendix shows frequencies of three kinds of harm events--bumping into obstacles, cane getting stuck, and tripping over obstacles for individual subjects.

Plotting a number of cane taps as a function of trial time, a reasonably straight regression line was obtained. Figures 25, 26, 27, and 28 show the regression lines for each group of subjects. Figure 29 shows the frequency of harm events for three conditions--quiet room, fans turned on, and white noise. In the free walk condition no harm events occurred. Likewise, when sighted subjects walked the obstacle course without blindfolds, no harm events occurred.

Table 5: Means of Cane Taps, Time (in sec.) spent Traversing the Course, and Harm Events for Four Groups of Subjects

Measurements	Groups of Subjects	Free walking course 170 feet +	Obstacle Course, 170 feet ++			
			Quiet Room	Fans	Earphone White Noise	No Blindfold
Means of Cane Taps	5 blind 1 cane	104	268	193	243	--
	4 sighted 1 cane	117	228	222	227	85
	4 sighted 2 canes	104	280	238	237	65
	2 sighted "T" cane	93 418	361 1137	284 937	265 972	107 257
Mean of Time in Seconds	5 blind 1 cane	63	258	179	223	--
	4 sighted 1 cane	76	205	209	205	56
	4 sighted 2 canes	71	262	201	182	54
	2 sighted "T" cane	115	344	245	210	68
Means of Harm Events	5 blind 1 cane	--	7	7	19	--
	4 sighted 1 cane	--	21	21	23	--
	4 sighted 2 canes		18	15	15	--
	2 sighted "T" canes		121	121	17	--

+ Means based on four walks of 170 feet segments for every subject.

++ Means based on three replications of each condition for every subject.

Table 6. Blind Subjects Using One Cane. Results for Each Trial of Cane Taps, Time (in sec.) and Frequency of Harm Events

Subjects		Free walk 340 feet		Obstacle Course								
				Quiet room			Fans			White noise		
J.H.	taps	150	152	153	147	139	139	119	118	256	303	265
	time	124	123	114	102	109	169	98	98	263	249	215
	harm	--	---	--	--	--	2	1	1	8	9	6
L.B.[+]	taps	287	230	449	353		266	243	247	347	256	273
	time	248	176	487	413		241	245	245	336	280	301
	harm	—	—	2	2		5	1	2	7	3	7
F.R.[+]	taps	232	216	343	275	240	211	201	192	232	234	233
	time	145	134	329	219	199	205	174	162	212	193	198
	harm	--	--	3	1	4	1	2	--	5	7	3
M.A.[+]	taps	261	198	415	273	231	253	182	171	193	193	171
	time	211	144	406	259	199	247	195	167	208	190	156
	harm	--	--	3	2	5	5	4	5	6	8	6
E. W.	taps	178		299	195	179	195	188	177	280	219	192
	time	131		214	167	210	169	146	133	227	173	147
	harm	--		4	5	6	4	2	2	10	4	6

[+] Female Subjects

Table 7. Sighted-Blindfolded Subjects Using One Cane. Results for Each Trial of Cane Taps, Time (in seconds), and Frequency of Harm.

Sub-jects		Free walk 340 feet		Quite room			Fans			Obstacle Course White noise			No blindfold
JD	taps	189	182	285	268	262	221	229	218	253	237	196	78
	time	174	137	337	265	232	190	195	190	213	197	171	51
	harm	--	--	8	6	5	6	7	2	10	8	4	--
JT	taps	209	225	205	174	182	187	222	202	222	205	215	--
	time	110	125	186	102	104	184	150	127	138	130	124	--
	harm	--	--	4	2	4	2	3	1	1	1	2	--
EN+	taps	237	--	243	269	201	238	226	269	269	241	235	96
	time	175	--	283	253	215	298	273	338	283	297	228	75
	harm	--	--	6	10	7	11	12	16	13	6	5	--
MM+	taps	228	201	227	223	195	236	209	203	245	190	197	82
	time	162	159	164	194	168	206	177	175	168	148	165	42
	harm	--	--	11	8	12	7	5	12	6	9	12	--

+Female Subject

Table 8. Sighted-Blindfolded Subjects Using Two Canes. Results for Each Trial of Cane Taps, Time (in Seconds), and Frequency of Harm Events.

Subjects		Free walk 340 feet		Quiet room			Fans			Obstacle Course White noise			No blindfolds
RC	taps	243		247	272	236	318	254	265	309	316	343	103
	time	217		323	267	244	301	231	298	244	234	244	85
	harm	--		4	4	6	7	8	3	2	3	4	
JH	taps	169	184	215	326	289	206	186	170	228	207	213	49
	time	126	141	152	248	194	148	138	140	158	149	150	46
	harm	--	--	6	5	2	6	5	6	5	11	9	--
BK	taps	256	175	337	321	265	226	228	178	232	213	180	66
	time	233	157	377	314	246	218	215	191	189	175	156	51
	harm	--	--	8	12	7	5	2	3	6	2	2	--
JC	taps	160	229	400	284	281	220	217	180	218	212	178	42
	time	156	136	385	259	244	192	187	158	173	173	145	35
	harm	--	--	9	5	6	6	8	3	8	3	5	--

Table 9. Sighted-Blindfolded Subjects Using "T" Cane. Results for Each Trial of Cane Taps, Time (in Seconds), and Frequency of Harm Events.

Sub-jects		Free walk 340 feet		Quiet room			Obstacle Course						No blindfolds
							Fans			White noise			
MC	taps	201	210	478	309	348	309	307	277	242	253	238	131
	time	291	165	409	230	245	213	227	179	172	165	141	76
	harm	--	--	3	2	2	3	3	2	2	4	1	--
JH	taps	273	251	351	303	379	329	252	225	303	297	259	83
	time	316	149	432	368	447	369	263	221	312	254	221	60
	harm	--	--	4	5	9	7	5	3	8	15	5	--

Table 10. Frequency of Harm Events for Individual Subjects

Subjects	Bumping into Obstacles	Cane getting stuck	Tripping over Obstacles
Blind (one cane)			
FR+	18	--	8
MA+	26	1	17
LB+	16	3	10
JH	12	--	15
EW	28	1	14
Sighted (one cane)			
JD	33	3	20
EN+	44	9	33
MM+	30	8	44
JT	12	5	3
Sighted (two canes)			
RC	21	4	16
JH	23	9	23
BK	24	10	13
JC	28	9	16
Sighted (T cane)			
MC	12	7	3
JH	35	4	22

+Female Subject

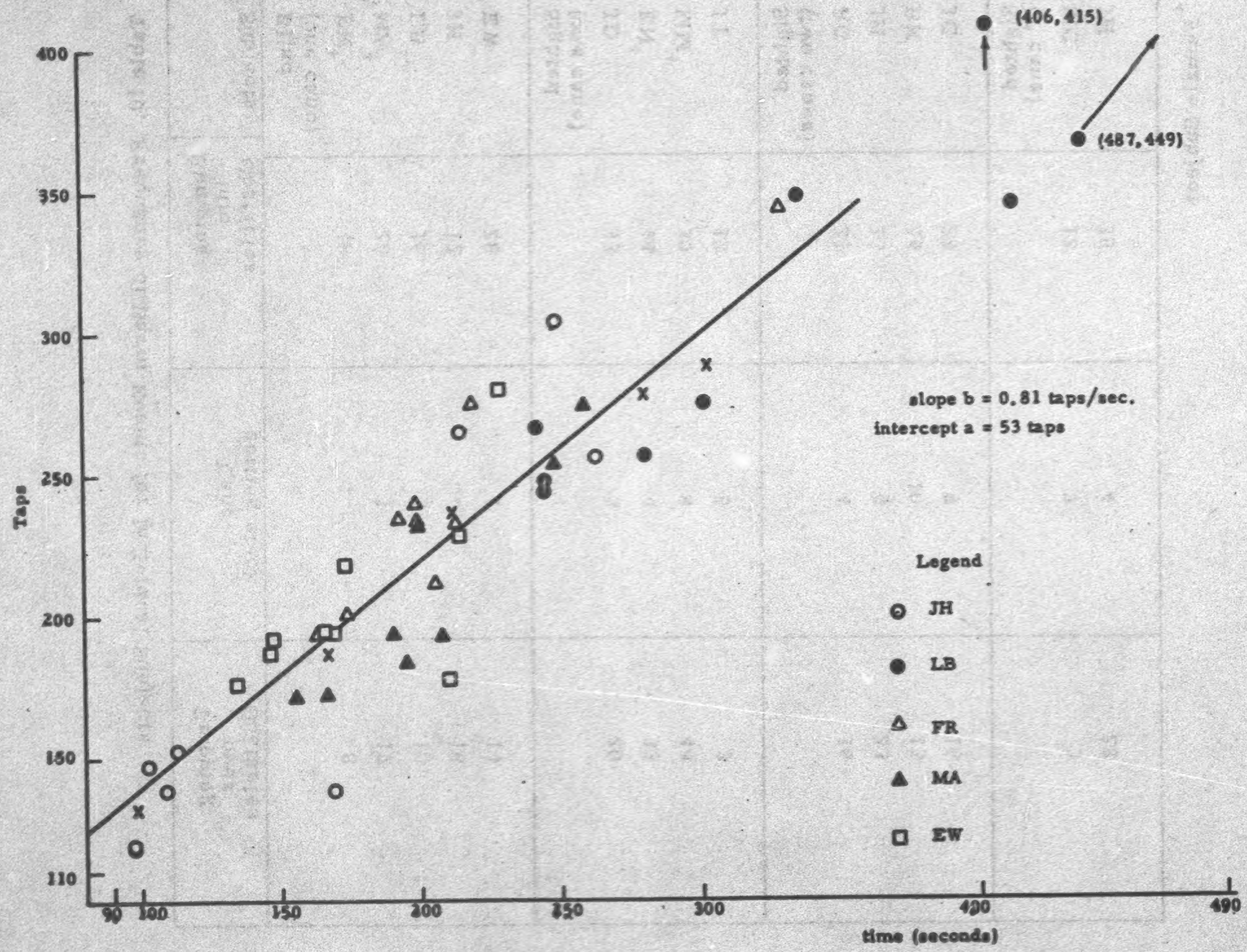


Fig. 25. Blind Subjects Using One Cane. Cane Taps as a Function of Time for Each Trial.

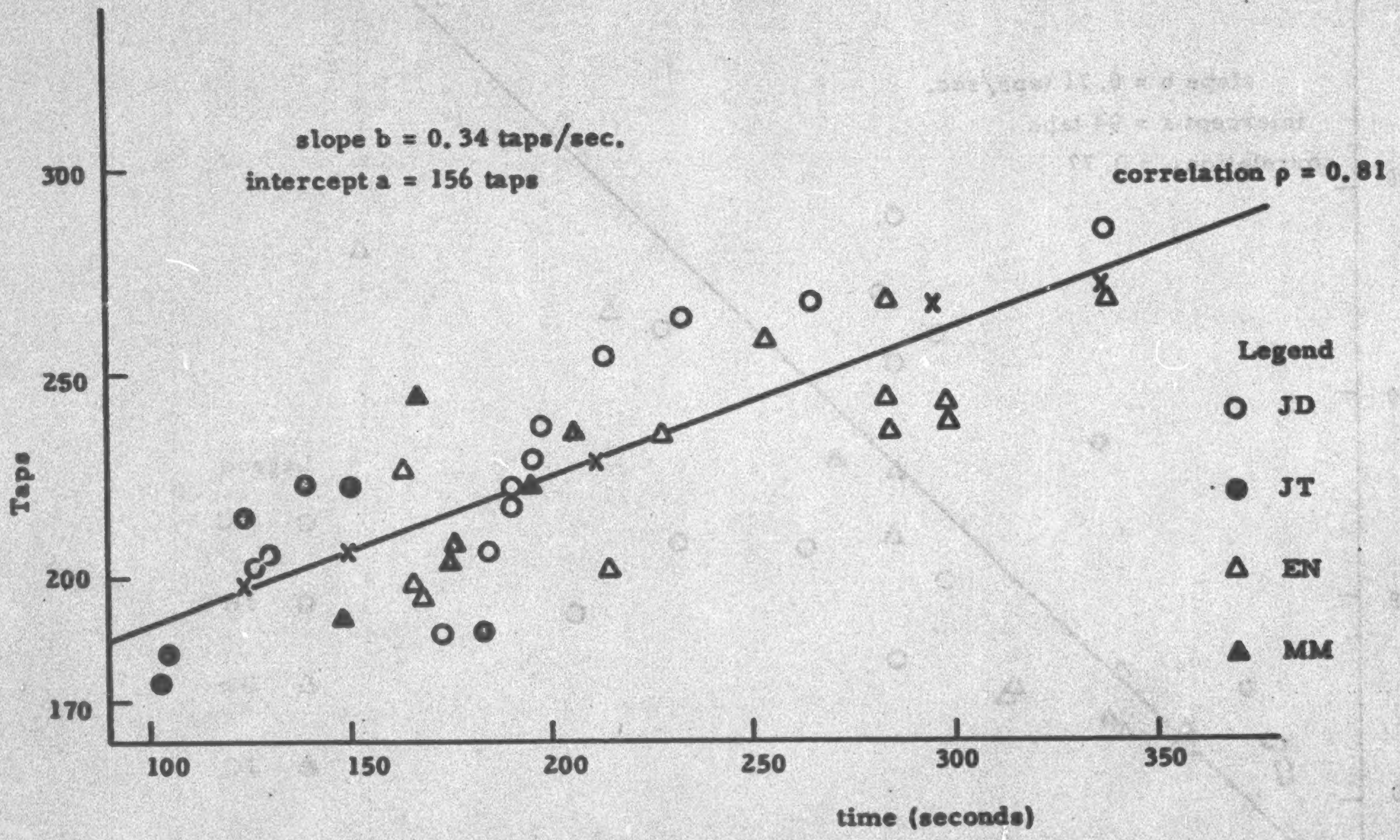


Fig. 26. Sighted-Blindfolded Subjects Using One Cane. Cane Taps as a Function of Time for Each Trial.

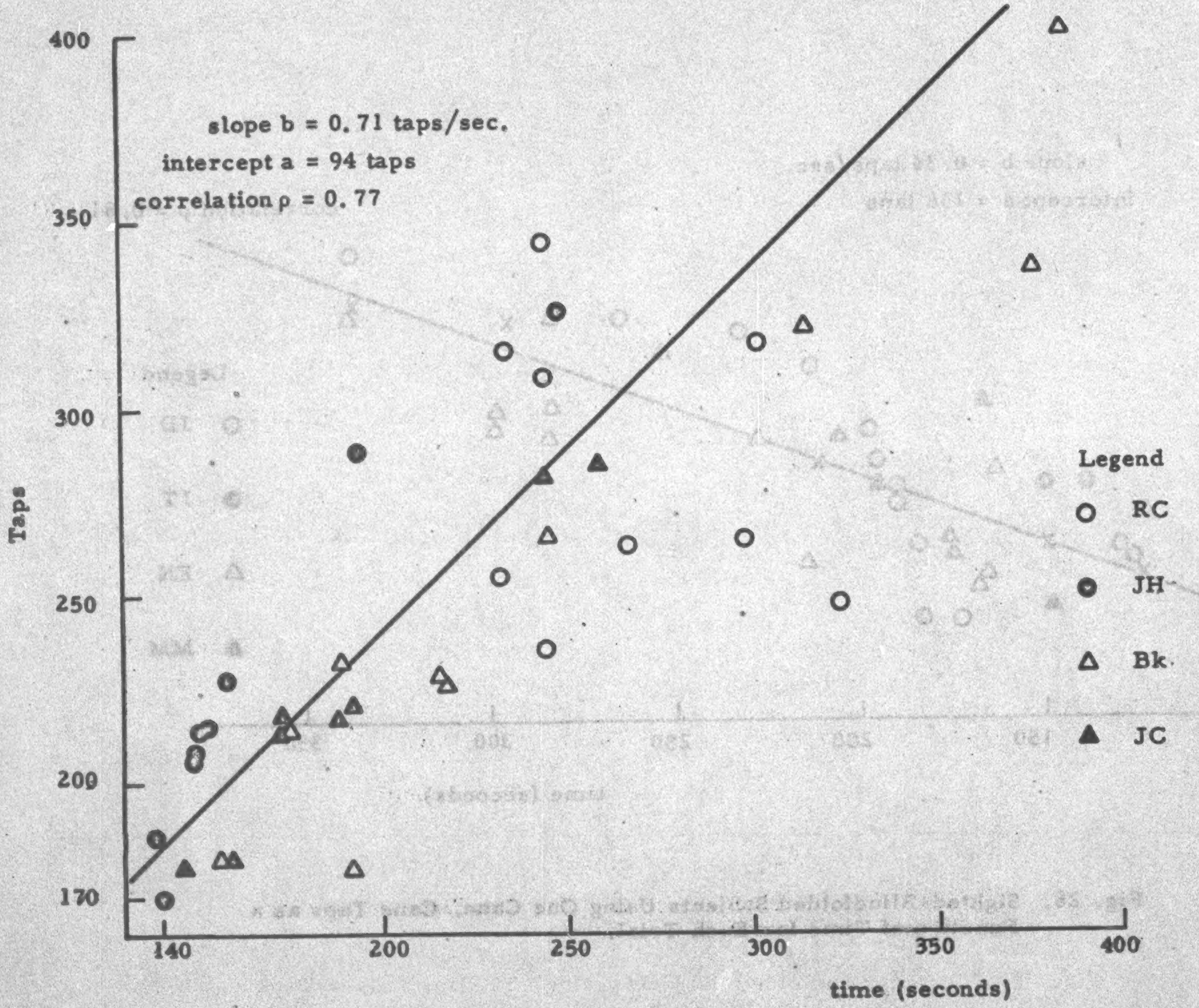


Fig. 27. Sighted-Blindfolded Subjects Using Two Canes. Cane Taps as a Function of Time for Each Trial.

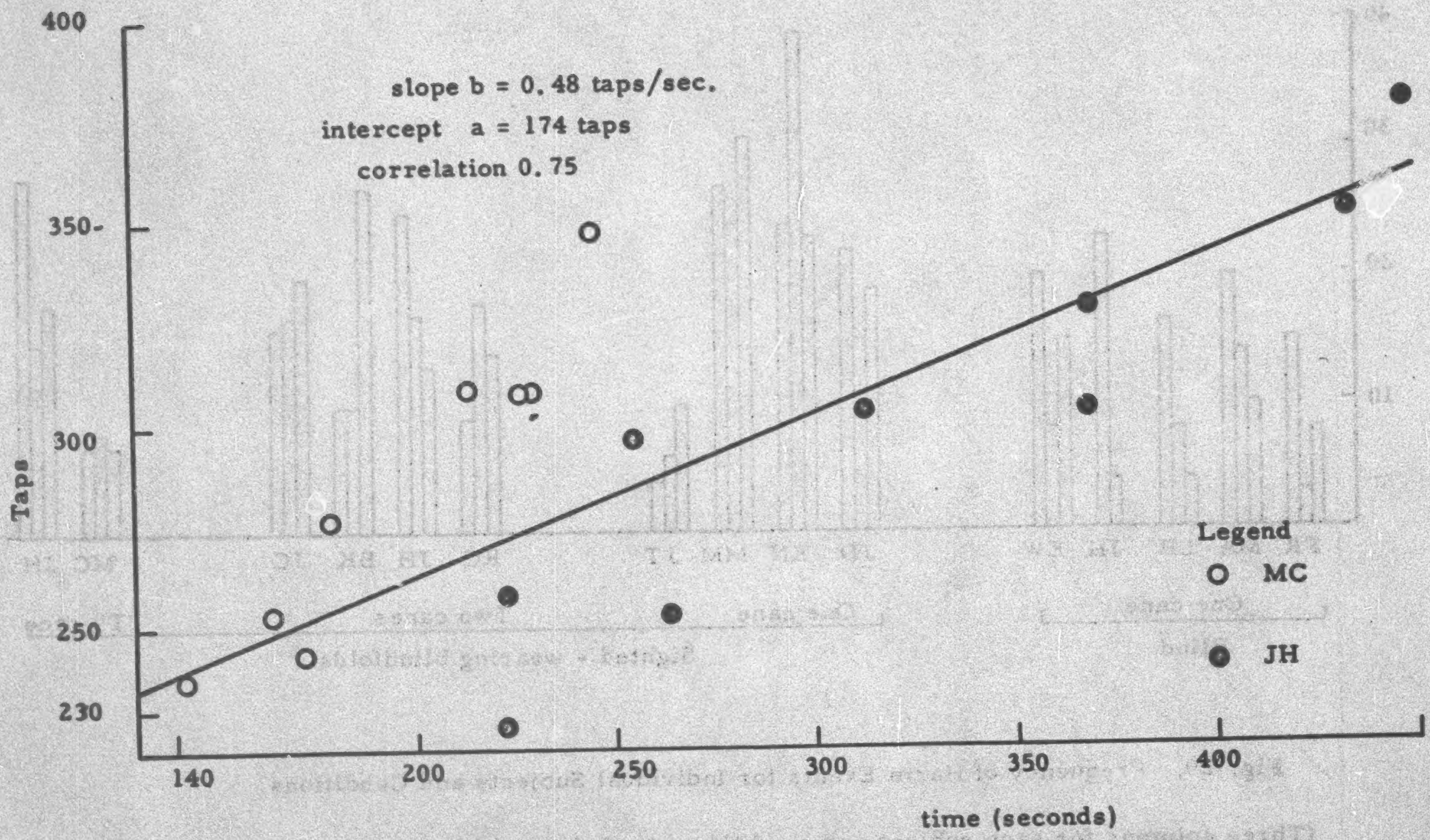


Fig. 28. Sighted-Blindfolded Subjects Using "T" Cane. Cane Taps as a Function of Time for Each Trial.

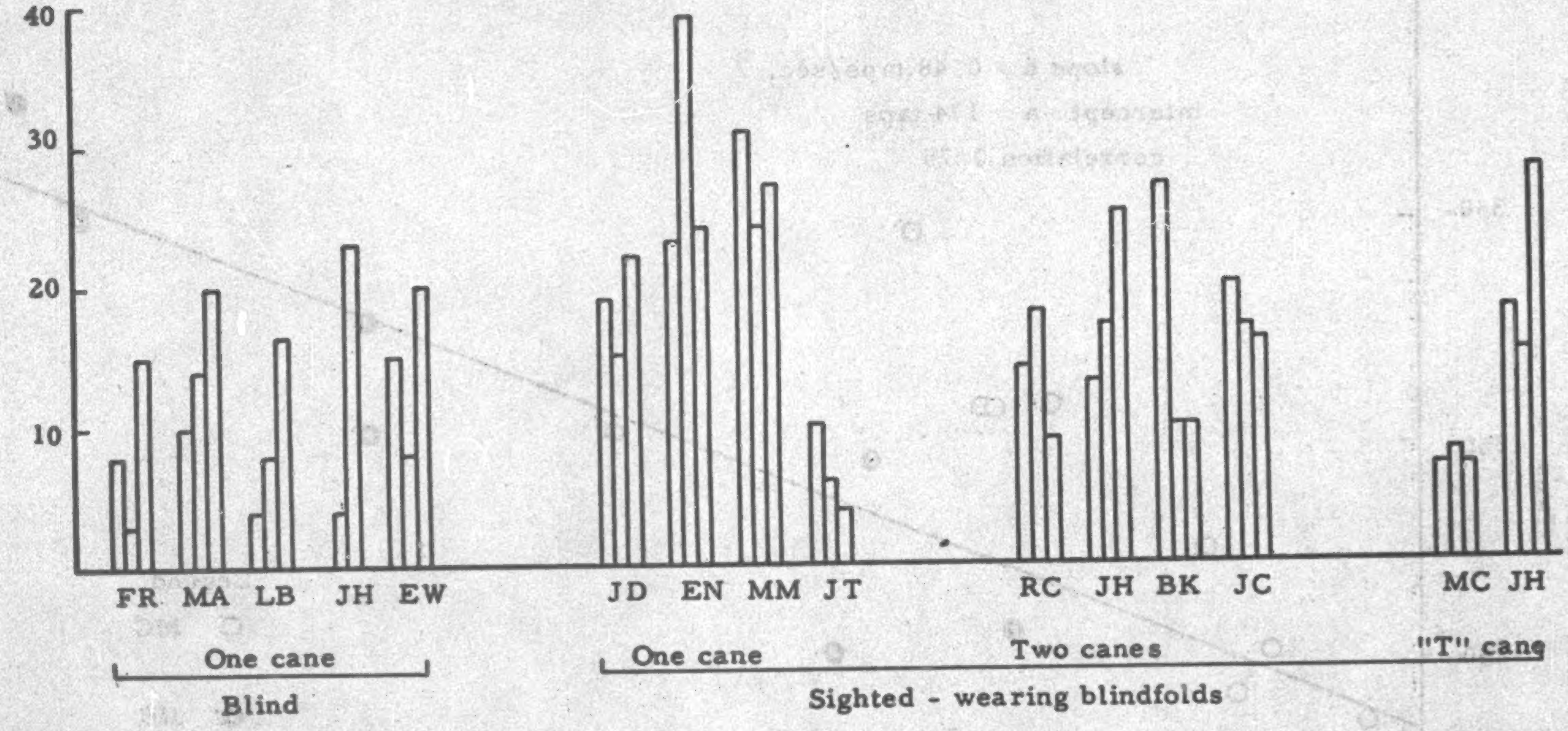


Fig. 29. Frequency of Harm Events for Individual Subjects and Conditions.

(Three columns for each subject and condition are, left to right, first condition - quiet room, second condition - fans, third condition - white noise.)

Analysis and Discussion of Results

An analysis of variance for taps, groups of subjects and conditions revealed significant differences among groups of subjects and conditions, both at the 95 percent confidence level. Figure 30 shows the arrangement for the analysis of variance.

Table 11 shows results of the analysis of variance for cane taps of four groups of subjects under three different conditions.

In a second analysis of variance for total traverse time, only conditions revealed significant differences at the 95 percent confidence level. The arrangement for analysis of variance for time is similar to that in Figure 30. Table 12 shows the results of this analysis of variance.

The significance of the "groups" effect is a rough indication at best, for it can be seen from the experimental design that the differences between blind and sighted, and between cane treatments within the sighted category were confounded. Looking to Table 5 with respect both to taps and time, the differences between blind and sighted appear about as large as the difference between cane treatments within the sighted category.

The same is true for the "conditions" effect which was significant with respect to taps. The "conditions" effect per se was confounded with order. From Table 5 it is seen that both taps and time tended to decrease from "quiet room" to "fans," which suggests either an experience improvement which was not offset by a performance decrement due to lost auditory cues, or that a small amount of ambient noise was actually useful and fewer taps were needed. Both taps and time increased again for white noise indicating a tendency to more taps and slower pace, in spite of any experience on other order effect.

Table 5 appears somewhat more revealing. Comparing for the course free of obstacles, the number of cane taps and the time with the corresponding measure for the obstacle course, large (not unexpected) differences appear. All subjects show at least doubling in both the average number of taps and average time for 170 feet of travel. This change in behavior may indicate two different uses of the cane. In the course which is free of obstacles the cane was probably used to confirm a strong expectation that the future environment was like that just encountered. In the obstacle course, the cane was probably used as a probe to find an open passageway. Because the prior environment was different from the future environment, small, independent segments of environment had to be examined in detail before one decided to move forward. To explore the environment in greater detail, more time and taps were needed.

Table 5 also indicates interesting behavioral differences between groups of subjects. The blind group seemed to be more sensitive to the environmental changes than the sighted-blindfolded group using one cane. But this "sensitivity" to conditions may have been due either to the acoustic masking conditions themselves or to the ordering of conditions, which was the same for every group. Only the group of sighted-blindfolded subjects who used the "T" cane indicate a consistent improvement through all conditions. The sighted-blindfolded group using one cane remained at a stable rate of tapping throughout all conditions.

Thus the tap and time measures leave us with no one dominant conclusion except perhaps that time and number of taps correlate through all treatments, Figures 25, 26, 27, and 28.

Table 5 reveals that the "harm events" measure differentiates the sighted from the blind groups. A chi square test for harm events among the four groups of subjects was

Table 11. Analysis of Variance for Total Cane Taps

Source of Variation	Sum of Squares	y	Mean Square	F
Groups of subjects (c)	27,203	3	9,068	3.91^{+}
Conditions (R)	18,060	2	9,030	3.89^{+}
(Cells)	(56,898)	(11)	--	--
Interaction (R x c)	11,585	6	1,931	0.83
Within Cells	76,545	33	2,320	--
Total	133,393	44	--	--

$^{+}$Significant at $P \leq 0.05$

Table 12. Analysis of Variance for Time (in seconds)

Source of Variation	Sum of Squares	y	Mean Square	F
Groups of subjects (c)	15,317	3	5,106	1.12
Conditions (R)	27,850	2	13,925	3.06^{+}
(Cells)	(64,152)	(11)	--	--
Interaction (R x c)	(20,985)	6	3,498	0.77
Within Cells	150,183	33	4,551	--
Total	214,335	44	--	--

$^{+}$Significant at $P \leq 0.05$

		Group of Subjects			
	Order of assignment	5 Blind Subjects one cane	4 Blindfolded one cane	4 Blindfolded two canes	2 Blindfolded "T" cane
Quite Room	1	Means of 3 trials of cane taps	---		
Fans	2	---	---		
White Noise	3	---			

Fig. 30. Arrangement of Groups of Subjects and Conditions for the Analysis of Variance.

2

significant ($P = 0.05$ $x^2 = 8.76$ with 3 df). The differences of harm events within the sighted group of subjects suggest that the cane provided to the user different information about the environment.

Observations during the experimental sessions and questioning of subjects revealed that the blind group and the sighted group used different criteria to detect and avoid obstacles. The blind group used "facial vision" to detect hanging obstacles. For example, the hanging platform was detected by most of the blind subjects at the end of six trials. When they received white noise through earphones, the blind subjects could not avoid bumping into the suspended platform. The sighted-blindfolded subjects rarely used, or knew the existence of the so-called "facial vision" cues. They apparently preferred to estimate the distance from prior objects to the suspended platform.

The group of subjects using two canes showed an entirely different pattern of cane use. One of the canes (usually in the nondominant hand) was reserved for maintaining continuous contact with the environment and was dragged along the floor, while the second cane was tapped in the conventional way.

A second chi square analysis of harm events was performed on the individual subjects within the blind group, and was significant ($x^2 = 9.32$ 4df).

Suggestions

Even with a very limited variety of characteristics by which to model the complex environment of the blind, the factors of experience and availability of cues in mobility may be studied profitably.

Wright (1961, p.4) suggested a 15 point mobility scale, to be used by the experienced observers to judge the behavior of the blind person. The successful observation of cane tapping, sensitivity to environment, and harm events in this study indicate that Wright's mobility scale could be expanded by including present measures--in particular, the "harm type" measurements. A scale of objective "success of travel" could be used to augment the subjective mobility rating scale. The present study has not provided enough data to work out a "success of travel" scale nor indices which would provide a sufficient measure of the cane user's ability to travel. Further experiments are suggested in order to refine the categorization and recording of "harm events."

V

INTERVENING VARIABLES AND ADJUSTMENT: AN EMPIRICAL DEMONSTRATION

by

Irving F. Lukoff and Martin Whiteman

EDITOR'S NOTE:

This paper is reprinted with permission of the National Association of Social Workers, from SOCIAL WORK, Vol. 7, No. 4 (October 1962), pp. 92-102.

Irving F. Lukoff is associate professor, Graduate School of Social Work, University of Pittsburgh. Martin Whiteman, Ph.D., is associate research professor, New York Medical College, New York City. Support is acknowledged from the Office of Vocational Rehabilitation, U.S. Department of Health, Education, and Welfare, with additional support from the American Foundation for the Blind and the Seeing Eye, Inc. In addition to the authors, the project staff at the New York School of Social Work, Columbia University, included Professor Samuel Finestone, Project Director.

There are several research approaches that characterize the study of adjustment. Most commonly such studies assume a similar analytical model: the multiple regression equation. A number of predictors are often assembled, including measures derived from personality inventories, judgments of therapists or counselors' ratings; sometimes demographic and social data may be included. Many classes of variables are associated with adjustment, and a number of techniques are available to determine the relative contribution of an assortment of predictors to the criterion variable, i.e., adjustment. Several variables are related to the criterion and the relative power of each variable to predict adjustment is thereby isolated. The combination of variables that accounts for the largest proportion of the variance is then retained to predict adjustment. The relative contribution of each of the predictors provides a method for assessing the significance of each predictor.

This same model may in fact be used without recourse to formal statistical techniques. Instead of using factor analytic techniques or multiple correlation methods to determine the weights to be assigned to variables, simple zero-order correlations are used (where each predictor is correlated with the criterion variable independently of the other predictors), although this always leaves open the question of redundancy between variables, e.g., education and intelligence quotient may be measuring about the same thing, and one thereby is in danger of attributing too much importance to one or the other variable.

This model when properly used can lead to very effective prediction. If the problem is to assess accurately who might be successful candidates for parole or therapy or sales positions, a fairly good prediction can be obtained when you have hit upon good predictor variables and you are certain your criterion variable is a good one.[1] But this model does not lead to the understanding of the causes of adjustment or to the unraveling of the nature of the contribution of each variable to the measure of adjustment. One reason for the resistance of this model to interpretation is the disparate nature of the predictors that effectively relate to the criterion, so that no simple explanatory scheme can account for all the correlations. Ad hoc interpretations, many quite plausible, can be made once the size of each variable's contribution to the prediction of adjustment is assessed; however, these are only preliminary steps in the scientific progression toward understanding and explanation.

---

[1] A good summary of the assumptions and utility of this model can be found in Paul Horst, The Prediction of Personal Adjustment (New York: Social Science Research Council, Bulletin No. 48, 1941).

An adaptation of the regression model attempts to compress the predictors into a more limited set of factors that account for the tendency of the predictors to correlate with the criterion. A factor or factors shared by the predictors is isolated by factor analytic techniques. These methods serve to reduce the number of predictors necessary, although it is in reality difficult to construct "factor pure" measures, so that in practice most of the initial tests and ratings have to be retained.

An alternate model, one demonstrated here, hypothecates a variable that "intervenes" between the predictors of adjustment and the achievement of different levels of adjustment. The intervening variable is one that can statistically account for the relationships between predictors and the criterion (adjustment in this instance). This intervening variable is one that may be derived from theoretical assumptions and, once measured, introduced into the analysis. Or, in some instances, it is a purely theoretical notion that is hypothecated in order to organize disparate observations.[2]

An intervening variable, as used here, is distinguished by the fact that the initial relationship of the predictors to adjustment is eliminated by the introduction of the intervening variable; e.g., intelligence may significantly correlate with adjustment until the intervening variable is introduced. Partialing out the original correlation by use of an intervening variable, if it in fact intervenes, will cause the original relation to decline (ideally, to disappear).[3] In effect, the intervening variable explains the initial association in that both the predictor and the dependent variable (adjustment) are related becuase of their mutual relation to the intervening variable. If a number of such correlates can be related to the same intervening variable, you can explain a larger number of propositions with a much more limited set of propositions, a goal of all theoretic inquiry.[4]

The research reported here utilizes as an intervening variable the expectations of the "role-set"; i.e., the standards of conduct various persons direct toward blind persons when they are part of the network of primary group relationships. The hypothesis, described more fully later, is that a variety of the usual predictors of adjustment are able to predict fairly well because they serve as indicators of the kinds of expectations likely to be directed at the respondents, blind persons with different levels of adaptation to their handicap.

---

[2] See Kenneth McCorquodale and P.E. Meehl, "On a Distinction Between Hypothetical Constructs and Intervening Variables," Psychological Review, Vol. 55 (1948), pp. 95-110. "Theoretical" notions that are not directly reduced to operations are distinguished from intervening variables that have some directly accessible link to measurement by the authors, who suggest the term "hypothetical constructs" for the former, reserving the term "intervening variables" for measurable entities serving an "explanatory" function.

[3] Most persons are familiar with the correlation between storks and birth rate, which is "explained" by the "intervening" variable "rural-urbanness." When rural-urbanness is controlled the relation of the number of storks to birth rate disappears.

[4] A more detailed statement of the nature of intervening variables is contained in P.F. Lazarsfeld, "The Interpretation of Statistical Relations as a Research Operation," in The Language of Social Research, P.F. Lazarsfeld and M. Rosenberg, eds. (Glencoe, Ill.: The Free Press, 1955).

The Analysis

The major hypothesis that guides this analysis attempts to wrest some uniformity from the multiple factors ordinarily associated with adjustment of blind persons. Obviously, an assortment of factors are associated with such adjustment: residual vision, intelligence, social class origins, ethnicity, age, personality traits, and so on. But this implication of multiple influences, though apparent from other investigations,[5] and from the findings to be presented shortly, fails to grapple with a number of problems of theoretical and practical significance. First, some way must be found that can organize these findings into a more compact series of generalizations, if it is at all possible. Second, most of the influences on adjustment are simply incapable of alteration or change, if their role is basic, for effective rehabilitation efforts. Neither intelligence, social class origins, nor, for the most part, the provision for some residual vision can be tinkered with by vocational counselors or social workers who counsel the blind.

The viewpoint presented here is that various predictors or factors associated with adjustment serve as proximate indicators of the environmental press that surrounds the blind person; in turn, the environmental pressures induce various degrees of adjustment. To illustrate: a partially seeing person may not have to face up to the protectiveness and solicitousness that a totally blind person is likely to encounter in his interaction with family and friends; a person whose social origins are middle class may find, generally, less paternalism and stronger expectations that he be independent, for example, than someone whose origins are lower class. Similar considerations apply to each of the factors ordinarily associated with adjustment.[6] Insofar as they predict different outcomes, they do so because of an intervening set of conditions: the attitude milieu that surrounds the blind person. Between social class, or age of onset, or residual vision, or the other factors that are associated with blindness, it should be possible, according to this hypothesis, to identify an attitude network that helps to explain the association between these factors and adjustment. If this hypothesis is satisfactory it will enable us to predict not only those instances where these predictors are correlated with adjustment; it will also enable us to explain those instances that depart from the usual predictions, whether it is the blind person with 20/200 visual acuity who is poorly adjusted, or the person with a college education who does not appear able to perform as well as most of his peers.

Source of Data

The information used in this analysis was derived from a sample survey of 500 legally blind persons in New York State.[7] The sample was limited to persons between 15 and 54 for two reasons: (1) to avoid an excessively aged sample, and (2) to provide a sample that deals with the problems of persons in the active years of life when the rehabilitation goals are more or less similar. With the co-operation of the New York State Commission for the Blind, it was possible to select a sample that was representative of the blind population in the entire state. With compulsory registration in force for fifteen years at the time of this survey, the vast majority of blind persons were in this register; only a negligible number of persons refused co-operation (22, or

---

[5] See War Blind Veterans in a Post-War Setting (Washington, D.C.: U.S. Government Printing Office, 1958); and Mary K. Bauman, Adjustment to Blindness (Harrisburg, Pa.: State Council for the Blind, 1954).

[6] A summary of extracts supporting this view may be found in Alan Gowman, The War Blind in American Social Structure (New York: American Foundation for the Blind, 1957), Chapter 1; and Jacob Twersky, Blindness in Literature: Examples of Depictions and Attitudes (New York: American Foundation for the Blind, February 1955).

[7] A more detailed description of the sample can be found in S. Finestone, Irving F. Lukoff, and Martin Whiteman, The Demand for Dog Guides and the Travel Adjustment of Blind Persons (New York: Columbia University Press, 1960), Appendix A, pp. 104-112.

4 percent, of the sample). The completed sample, when contrasted with the total register, showed a close correspondence in sex, age, and duration of blindness, so that the sample could be assumed representative of New York State legally blind persons within the designated age span.

Some Problems of Measurement

To present this analysis we have to discuss three classes of information. First, it is necessary to know how adjustment is being measured;[8] second, how the attitude network surrounding the blind person is indexed; and third, what classes of predictors associated with blindness are used to test the hypothesis.

A. Adjustment. Adjustment is a complex concept that shares almost as many meanings as there are persons attempting to cope with adjustment. Although various subjective elements can enter into the concept, such as feelings of personal satisfaction and well-being, the index proposed here focuses, instead, on the behavior of blind persons. This focus is justified on several grounds. First, where relevant, it can be related to personal evaluations of well-being or psychological health. Secondly, the focus of rehabilitation centers and others concerned with adjustment is on the performance of blind persons as workers and as normal members of families and neighborhoods. In addition, by dealing with actual performance, the difficult problems associated with a more psychologically based concept are circumvented. Problems of reliability and meaning are less likely to be questioned. And it is fundamentally the outcome sought in all rehabilitation efforts, and the "pay-off" even for psychological concepts of adjustment.

The typology of adjustment is derived from four behavioral samples: (1) employment, (2) travel independence, (3) independence in eating, and (4) independence in shopping. These four components were selected since they involve behavior in significant contexts, and characterize the individual in even more extensive ranges of behaviors. Each component was selected on the assumption it reflects, in some measure, a variation in behavior along a dimension of independence-dependence. They also involve the person in a fairly wide range of significant activities which can then be reasonably assumed to characterize the persons under study.

1. Employment. Strictly speaking, this component, the most heavily weighted, is not an employment index per se, since students and housewives were included. A series of questions were asked about employment at the time of the interview. The responses were classified to distinguish persons engaged in independent professions and competitive industry on the one hand, from those in sheltered workshops and traditional crafts associated with the blind on the other. The heaviest weight was given the first group, followed by the "other employed." The unemployed were given no weight for this component.

Married women were classified by their score on an index based on an inventory of household skills, while students attending school full time (mostly college), were arbitrarily assigned into the top group, on the grounds their current performance reflected an active, independent orientation comparable to the independent professionals and those engaged in competitive industry.

---

[8] See the typologies developed by Thomas D. Cutsforth, The Blind in School and Society (New York: American Foundation for the Blind, 1951); and Irving F. Lukoff, "A Sociological Appraisal of Blindness," in Social Casework and Blindness, S. Finestone, ed. (New York: American Foundation for the Blind, 1960). One "type" of adaptation is studied by Alan Gowman, op. cit., where he interviews independently oriented blind war veterans. The index of adjustment can be considered an index of social role, i.e., it characterizes the role performance of a blind person in a variety of fundamental social relations. Role also serves to direct attention to various useful hypotheses derived from role theory. In this paper, however, it will be identified as adjustment in order to confine the issues to a single hypothesis.

2. Travel Efficiency. This index was derived from three separate scales: independence of travel, extensiveness of travel, and frequency of travel. The top third on this combined index was weighted most heavily, while the bottom group received no weight.

3. Independence in Shopping. Three items concerned with shopping were assembled into an index. These include: does respondent shop for himself; does he go shopping alone; does he handle money. The scores were weighted in the same way as the travel efficiency index.

4. Independence in Eating. Seven items were cumulated into a score, including questions of whether respondent eats alone in restaurants; if he asks waiter for help; whether he prefers to locate dishes for himself; does he prefer to identify the food by himself; if he wants someone to tell him where the food is on the plate; whether he cuts the meat himself; and if he prefers to pour water, coffee, and the like for himself.[9]

The four components used in constructing the typology are all positively associated with each other to a statistically significant extent, although the correlations are, in some cases, modest. One factor to take into account is the tendency for females, who were mainly classified by the household competence index, to dampen the correlations. Employment is a much more rigorous criterion of independence than the ability to iron, or cook, or to sew. Thus, travel efficiency correlates with the index of household competence with a modest C-coefficient of .13, while employment classification correlates .39 with travel efficiency.

The scores for each person were assembled into four groups: I, the Independent Blind; II, the Moderately Independent; III, the Moderately Dependent; and IV, the Dependent Blind.

B. Primary Group Attitudes. If attitudes are significant for the blind person they must first be perceived by him. Thus, the information on attitudes is assembled from reports the respondent made on attitudes held by various persons he knows. The obvious danger is that this may simply reflect his own values, and thus we are only measuring the projected standards of our respondents. A series of internal checks renders this hypothesis untenable. In fact, there is a great deal of variability in the attitudes respondents report in different sectors, such as travel or employment; and the different groups (family, friends--both sighted and blind--and employers) differ from each other quite markedly. The projective hypothesis would only be consistent with a great deal of similarity in individual reports of the standards of different groups and in various behavior sectors. Then, the analysis (not reported here) was replicated, controlling for each person's own preferences, and the findings remain substantially unaltered.[10]

A series of questions were asked about the attitudes (or expectations) that the respondent perceived in four areas: travel, employment, having sighted friends, and taking care of one's needs. They were then asked how their families felt about this, their sighted friends, their blind friends, and employers. Thus, an individual could report there were four groups, three, two, one, or no groups that favored independence. Some experimentation with different combinations showed that no predictive efficiency was obtained by combining all responses, so that only the responses to one item were used in this analysis: whether each group felt the respondent could meet all his needs while making a trip.

---

[9] For a more detailed description of each of the scales described see S. Finestone et al., op. cit., Appendix B.

[10] A separate report will be made on a person's own attitudes and the relation to primary group attitudes and adjustment.

TABLE 1. C-COEFFICIENTS BETWEEN COMPONENTS OF ROLE TYPOLOGY

	Indep. in Eating	Indep. in Shopping	Travel Efficiency	Occupational Classification
Indep. in Eating	...	.26[b]	.45[b]	.20[a]
Indep. in Shopping	...	...	.35[b]	.17[a]
Travel Efficiency	...	...	...	.24[b]

[a] $.02 > p > .001$ [b] $p < .001$

In effect, we have an index of role-set, i.e., whether the persons with whom the respondent is in constant interaction are agreeable in favoring independence, whether variable, or whether they tend to denigrate the respondent's ability to take care of his needs.[11]

C. The Predictor Variables. A sample of variables was selected that are ordinarily associated with adjustment, not only for blindness, but for other handicapped groups (with the exception of residual vision). Each variable, with one exception to be noted, correlated with the adjustment typology. Sound reasons can be advanced for the correlations in each case; however, for this analysis they will not be pursued in detail, although each correlation obviously plays a significant role on its own. The variables were selected because they can be assumed to reflect a wide range of experience. These variables are of two types: (1) those reflecting background experiences significant for socialization or social group membership; and (2) those that are more clearly personal attributes of the blind person.[12]

The background variables include: education, age of onset of blindness, ethnic group, and father's occupation (as an indicator of social class origins).[13] The personal attributes used in the subsequent analysis are vision, age, sex, and intelligence.

Findings

Each of these variables is associated with the index of adjustment. For brevity, only the general pattern will be reported, mostly quite predictable from other studies of adjustment:

1. Those with higher educational achievement were more frequently found in Type I (Independent) than those with less education.

2. The earlier the onset of blindness, the greater was the likelihood of an independent pattern of adjustment.

3. Blind persons who are white and of native-born parentage were more likely to be independent than whites of foreign-born parentage; Negroes, in turn, had the poorest adjustment.

4. If parents held white-collar jobs, there was a greater tendency for independent adjustment than for the offspring of skilled workers; unskilled parentage was associated, generally, with modest or poor adjustment.

5. Blind persons with residual vision were more independent than those who have only light perception, or who are totally blind.

---

[11] A separate analysis, to be reported elsewhere, is made of the different groups and their relative significance to the respondent's adjustment.

[12] This distinction is, in part, arbitrary, since some variables, such as age or ethnic membership, may index both current "attributes" and background experiences. The classification is simply heuristic, and only a detailed analysis of each variable can settle the question of the appropriate classification.

[13] Father's occupation is used in lieu of social class to avoid redundancy with the adjustment typology, which contains the respondent's employment, an ingredient for a social class index.

6. Younger persons fared better than older blind persons.

7. As intelligence increased the proportion who are independent rose markedly.

8. Sex, because of the indexing procedure used in developing the typology, showed no relation to adjustment. It is included because it is a significant variable that plays an obvious role in the kinds of standards society is likely to establish, and is important in subsequent phases of the analysis of the data from this study.

Test of the Hypothesis

The hypothesis states that each of the above variables predicts adjustment because each is a rough indicator of the attitude milieu faced by blind persons. We will examine first the relation of this attitude milieu, as evidenced by the number of groups that favor independence, to the adjustment typology; this will be followed by an examination of the relation of the number of groups favoring independence, and the adjustment typology, when the predictor variables are statistically controlled. If the hypothesis is supported, the relation of attitudes and adjustment will hold up, despite the elimination of the influence of these predictor variables. If these variables were the significant predictors, the relationships suggested here would not appear. Thus, if younger persons report that the persons with whom they interact do not expect independence, they should be poorly adjusted, despite the generally better adjustment pattern of younger persons; similarly, older persons who report group standards favoring independence will in fact be independent more often, despite the tendency for older persons generally to be in the poorer adjustment categories.

As can be seen in Table 2, there is a strong relationship between the number of groups that favor independent behavior and the distribution into the adjustment typology. Where the respondents report no groups favoring independence, 16 percent are in the independent group; however, where 3-4 groups are reported favoring independence, 52 percent are in the most independent group. At the other end, those with no groups to report are more often in the most dependent group.

TABLE 2. RELATIONSHIP BETWEEN NUMBER OF GROUPS FAVORING INDEPENDENT BEHAVIOR AND ADJUSTMENT *

		Number of Groups Favoring Independent Behavior		
Adjustment		None	1-2	3-4
(Indep.)	I	16%	33%	52%
	II	27%	31%	23%
	III	33%	27%	17%
(Depend.)	IV	24%	9%	8%
Total		100% (245)	100% (135)	100% (120)

* $p < .001$ as tested by chi-square

The relationship in Table 2 is suggestive of the thesis that perceived attitudes in the environment, as reflected by the number of primary groups that favor independence, are significant for the achievement of independent adjustment by blind persons. As the number of such groups increases, there is a steady increase in the achievement of independent adjustment.

However, as noted in the list of various predictors associated with adjustment, a variety of such correlates can be located. The problem is to find whether primary group attitudes are significant in their own right for predicting adjustment. For example, what happens to a person who is at the unfavorable end of one of the predictor variables when the attitudes in his primary group are favorable?

One sequence, the relation between education and adjustment, is presented in Table 3. A strong relationship is seen to exist between educational attainment and adjustment. There are over 2½ times the proportion in the most independent group who have some college, as compared to those who never went beyond grade school. At the

TABLE 3. DISTRIBUTION INTO ADJUSTMENT TYPES FOR DIFFERENT EDUCATIONAL LEVELS*

Adjustment		Educational Level Completed Grade School or Less	 Some H.S. and H.S. Graduates	 Some College through Post-Grad
(Indep.)	I	18%	31%	50%
	II	17%	34%	32%
	III	38%	24%	13%
(Depend.)	IV	27%	11%	5%
Total		100% (184)	100% (218)	100% (93)

* $p < .001$ as tested by chi-square

other extreme, there are more than 5 times the proportion in the most dependent group who did not go beyond grade school, as compared to those with at least some college. Those who attended high school fall between the grade school and college group.

It is apparent, then, that both education and primary group attitudes are strongly related to adjustment. The problem still remains to identify the extent attitudes are able effectively to predict adjustment, whatever the status of respondents' education.

TABLE 4. PROPORTION REPORTING TWO OR MORE GROUPS FAVORING INDEPENDENCE AND ADJUSTMENT; CONTROLLING FOR EDUCATION

Education	Adjustment I Independent	 II	 III/IV Dependent	Total
	(Proportion Reporting at Least Two Groups Favoring Independence)			
Completed Grade School or Less	53% (34)	35% (31)	16% (119)	(184)
Some High School and H.S. Graduates	54% (68)	34% (73)	27% (77)	(218)
Some College through Post-Graduate Work	56% (46)	33% (30)	29% (17)	(93)

All three types of information are tabulated simultaneously in Table 4. This permits an assessment of the relation of adjustment and "attitude milieu" when education is controlled. In Table 4, the proportion who report two or more groups favoring independence is indicated for each educational group and for the several role types. Note that approximately the same percentage in Type I report two or more groups favoring independence for each education category. The range is from 53 percent for those with grade school or less to 56 percent for those with at least some college. As the degree of independence declines, the proportion reporting two or more groups favoring independence drops sharply. Thus, there is no important difference between each of the education groups. However, the reason for the original correlation between education and adjustment can be observed by looking at the frequencies (in parentheses): those with little education are likely to report fewer persons expecting independence than college graduates (with the high school category in between). There are three times as many persons in Type III/IV among those with less education than in Type I; these ratios are almost reversed with the college group.

Table 4 indicates that the relationship between attitude milieu and adjustment is similarly patterned for the three educational groups. Persons with low education achievement who manifest a good adjustment are about as likely to report a favorable attitude climate as those with higher educational achievement. Conversely, even those with high educational achievement who report few environmental supports for independent adjustment are likely to be found in the more dependent categories.

Although the pattern is less than perfect, there is a clear and observable tendency for attitudes to play a considerable role in the adjustment achieved by this sample of blind persons. It can be seen that the independently adjusted, irrespective of their education, tend to derive from primary group networks that favor independence; the less well adjusted, on the other hand, tend to report few or no such group reinforcements for independent behavior.

Thus, the correlation of education with adjustment, despite its strength, cannot eliminate the influence of the attitude milieu. If education played a causal role, then the less educated would be in the poorly adjusted group irrespective of the number of groups favoring independence. Instead, all three educational groups show a similar pattern, as can be observed in Table 4. If education operated independently of the attitude milieu there would be a tendency for each of the educational groups to have a constant proportion favoring independence, irrespective of the actual adjustment of the respondents. However, this is clearly not the case.

In order to examine the same set of relationships for the other predictor variables, an alternate device is presented in the cause of brevity. On examination of Table 4, it can be seen that if plotted on a graph, all three educational groups would present very similar curves. All three educational groups would have a downward sloping curve if the vertical or Y-axis contains the proportion who report two or more groups favoring independence and on the horizontal or X-axis are plotted the adjustment categories. If the pattern is similar to the one we observe with education, the curves will all slope in a similar way. In the upper left hand corner of the first set of graphs, the data in Table 4 are presented in graphic form. The similarity of the slopes of all three curves indicates that the relationship between attitude milieu and adjustment is operative, although the influence of education is controlled. Thus, attitudes operate independently of education.

CHART I. PROPORTION WHO REPORT TWO OR MORE GROUPS FAVORING INDEPENDENCE; CONTROLLING FOR VARIOUS FACTORS RELATED TO ROLE TYPOLOGY

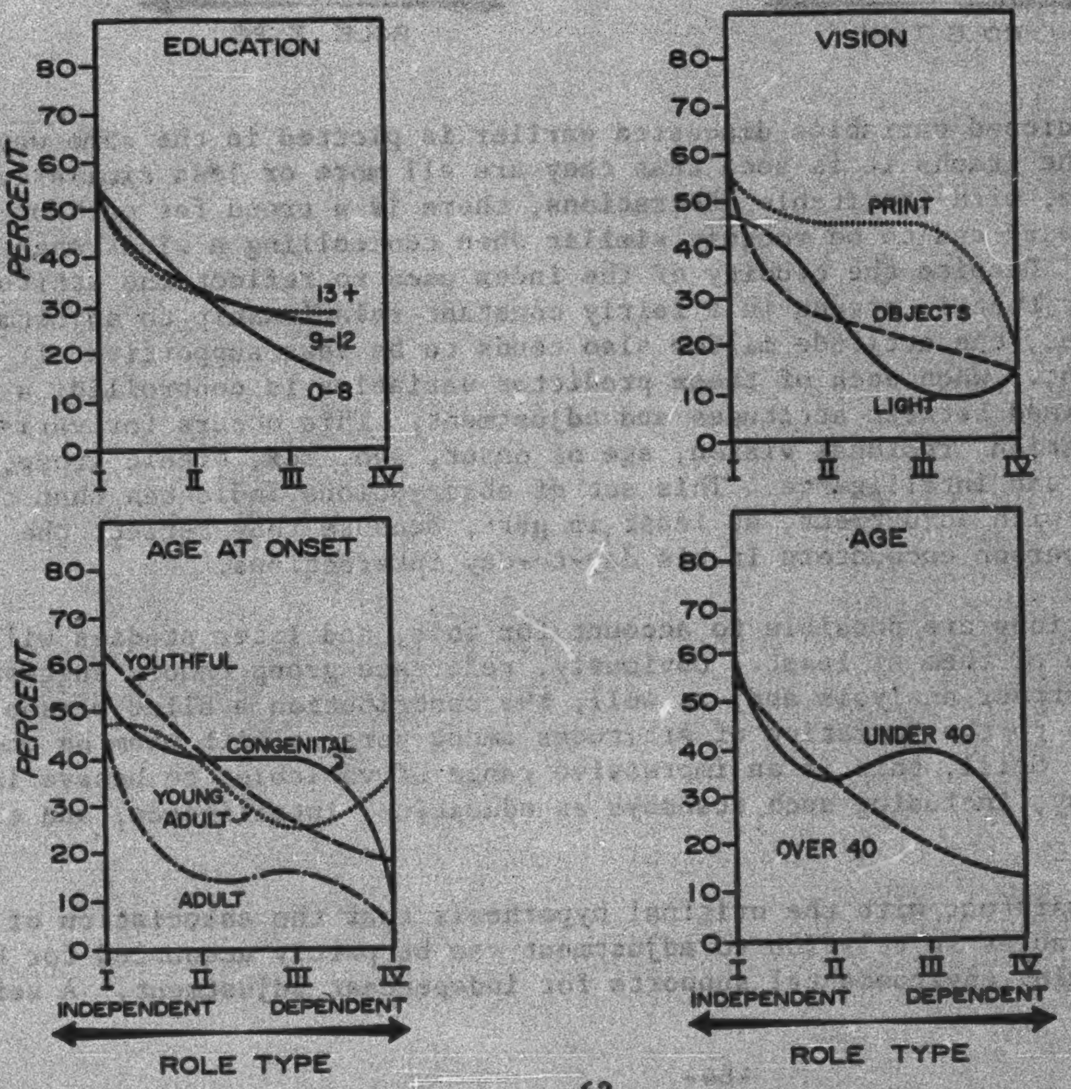
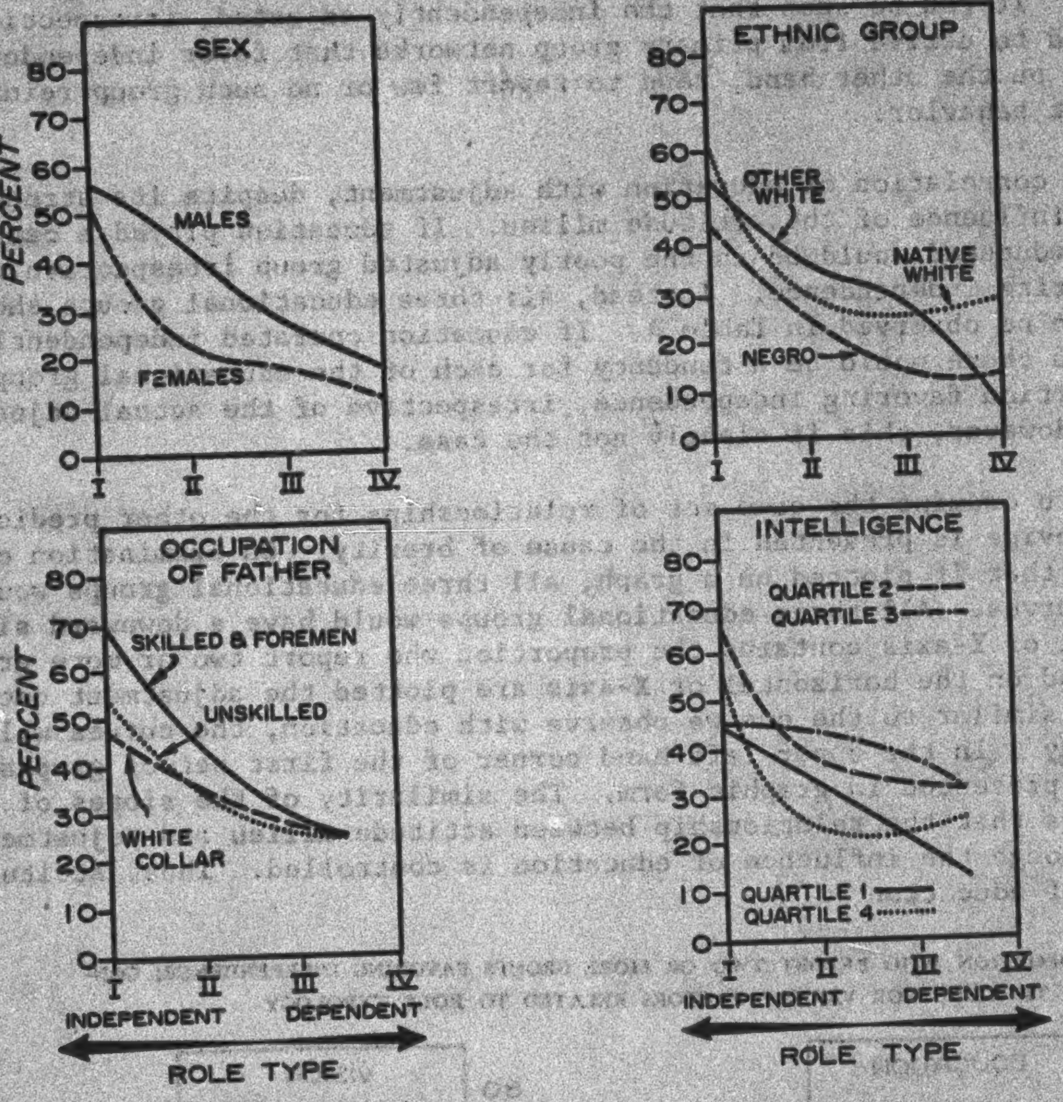


CHART II. PROPORTION WHO REPORT TWO OR MORE GROUPS FAVORING INDEPENDENCE; CONTROLLING FOR VARIOUS FACTORS RELATED TO ROLE TYPOLOGY



Each of the predicted variables discussed earlier is plotted in the same way. If we examine each of the graphs it is seen that they are all more or less similarly patterned. In each case, with inevitable aberrations, there is a trend for each of the curves to slope downward and to be roughly similar when controlling a wide range of predictor variables. Despite the crudity of the index used to reflect the attitude milieu it is apparent that it stands in a fairly constant relationship to adjustment: as adjustment declines, the attitude milieu also tends to be less supportive of independent adjustment. When each of these predictor variables is controlled, a visible relationship is retained between attitudes and adjustment. This occurs for variables as disparate as education, residual vision, age of onset, age, sex, ethnic group, father's occupation, and intelligence. This set of observations indicates that these predictors correlate with adjustment, at least in part, because they reflect the group standards the blind person encounters in his day-to-day interactions.

Several explanations are possible to account for this, and later studies will be made to sort out some of them at least. Obviously, reference group theory suggests some direction for further analysis and, as well, the contribution a blind person's own behavior may make to the formation of attitudes among persons with whom he engages in social relations. Still, this is an impressive range of variables to behave in such a markedly uniform way, including such standbys as education, intelligence, and class origins.

The data are consistent with the original hypothesis that the association of each of the predictor variables in relation to adjustment can be partly accounted for by virtue of their indexing environmental supports for independent adjustment. A series of relationships can now be encompassed by a single hypothesis, and some understanding of the way these variables function in relation to adjustment is clarified. Needless to say, not all of the relationships are completely accounted for, but a significant advance in understanding has been made that lends itself to systematic inquiry. The utilization of an intervening variable that can plausibly connect a wide array of predictor variables has clear advantages over alternate models in that it contributes to the summarization of a number of relationships, although it may be weaker with respect to the ability to predict empirically different levels of adjustment.[14] The further use of this framework for the study of adjustment appears warranted by the findings in this investigation, with alternate population groups and measurement techniques, and using other hypotheses, in order to increase systematic understanding.

---

[14] The analysis here could be replicated using correlation techniques; however, the typology and scales are such that only dubious increases in accuracy would be obtained.

VI

THE NEED FOR SENSORY DEVICES MARKET RESEARCH

by

Hyman Goldstein, Ph.D.
Chief, Biometrics Branch
National Institute of Neurological
Diseases and Blindness
National Institutes of Health

DITOR'S NOTE:

This paper was presented before the Sensory Research Discussion Group, Massachusetts Institute of Technology, Cambridge, Massachusetts, December 19, 1962.

As a statistician it may be perhaps presumptuous of the author to attempt to point out ways in which sensory devices may prove to be more useful to the blind, the consumers for whom they are designed. He is not an expert either in the development or manufacture of such devices. However, he is intrigued by the tremendous ingenuity and hard work that has gone into the development of these devices. The only reason for this paper is to help in some small way to assure that these devices will succeed in their ultimate objective and be of usefulness to a majority of the blind that can utilize them effectively.

The author's first contact in more than a passing way with this area was when he attended, upon invitation, the International Congress on Technology and Blindness sponsored by the American Foundation for the Blind and other agencies, voluntary and Government, held in New York City in June 1962. This Congress consisted of a number of panels devoted to broad aspects of the technology of device instrumentation. The two panels to which he devoted most of his attention were one on "Man-Machine Systems," chaired by Dr. Samuel J. Mason of Massachusetts Institute of Technology and another on "Living Systems," chaired by Dr. W. Grey Walter of The Burden Neurological Institute, Bristol, England. One of the major objectives of the Congress was to facilitate the exchange of information on devices designed to aid in the mobility and communication of the blind and severely visually handicapped by utilizing cues from remaining sensory modalities. In this objective, the Congress succeeded admirably! It brought together in one place specialists from many lands and many disciplines. For the first time individuals working in the various specialties concerned with such devices for the blind met and compared notes in the form of informative and well-prepared papers. There was evident the tremendous amount of work, effort, time and money that had gone into and will continue to go into the development of these devices. One could not help but admire the instrumentation discussed at this meeting and especially the great and continuing efforts that are being made to find ways of using the remaining sensory modalities, particularly hearing and touch, to provide additional adaptability for the sightless.

The author was greatly impressed, on the one hand, by descriptions of electronic canes, magnetic compasses, ambient light obstacle detectors, and reading machines, to mention just a few, and on the other hand, by mathematical models of simulated living systems dealing with vision, audition, and speech. These represented great effort and achievement by physicists, psychologists, engineers, mathematicians, physiologists, and other professions. But curiously enough, very little was said during the Congress about the size and characteristics of the consumer population such devices are designed to serve, or about actual or anticipated problems in the use of devices by such a population.

If the developers of devices are viewed as manufacturers or producers and the blind population, for whom these devices are being designed and developed, as consumers, it might be possible to get a clearer picture of the needs of the blind in this area. Perhaps the title of this presentation should have been "The Need for Sensory Devices Consumer Research." The author is not only interested in consumer characteristics but also in consumer reactions and attitudes over time. In his opinion, the kinds of data needed are, in reality, the kinds of data that the manufacturer of a new product or of a modification of an old product would seek to determine about the potential users of the product. These fall roughly into three groups:

1. Factual data are needed regarding the size and demographic characteristics of the consumer population, in this case, the blind and those with severe visual handicaps. Since the population is not static but is continually changing its character, such information should be obtained periodically to secure changes in size and distribution by age, sex, and race. It appears that the blind population is increasing almost twice as fast as the general population. Estimates quoted by Dr. Eric Josephson of the American Foundation for the Blind at the 1962 annual meeting of the American Association of Workers for the Blind indicated that since 1940 the blind population has increased 67 percent while the general population has increased only 36 percent. From the few statistics available on limited samples of the blind, as well as on other data, it is known that the blind do not constitute a representative sample of the general population. For instance, it was also brought out by Dr. Josephson that almost half of the blind are 65 years and over. This should be compared to the 9 percent aged 65 years and older in the United States' general population in 1960. The percentage of Negroes in the blind population exceeds considerably the percentage of Negroes in the general population. The difference then between the blind and the sighted population is not solely one based on vision.

One way in which data on the demographic status of the blind population on an annual basis may be secured is inherent in the recent establishment in this country of the Model Reporting Area for Blindness Statistics,[1] consisting at present of 10 states, under the sponsorship of the National Institute of Neurological Diseases and Blindness. This Area has the cooperation and support of the American Foundation for the Blind, the National Society for the Prevention of Blindness, and the Public Health Service. It is a voluntary association of states, maintaining registers of the blind, that have agreed to observe certain standards, including the adoption of a common definition of blindness. This will ultimately make possible the production of comparable and poolable statistics on visual acuity and causes of blindness in these states and in others that join the Area. The Model Reporting Area, furthermore, has the potential, with the cooperation of member states, of furnishing by age, sex, race, etc., on a regular or cyclical basis, information on services provided, such as mobility training, talking book machines, and so forth, as well as information on the presence of diseases and handicapping conditions, including defects of other sensory channels.

2. Information is necessary on the minimum sensitivity required for effective use of devices utilizing the specific modalities. "Sensitivity" is used loosely here to refer to acuity, discriminatory power, localization, etc. It is well to remember that not all blind persons need or can use devices. Some of them have enough vision left to enable them to travel, or to read with the help of low vision aids. Others are home-bound or bedridden. In addition, there are some non-blind that can very effectively make use of devices.

A modality often used to substitute for vision is hearing. In this connection, information must be secured as to the extent that aging per se jeopardizes the ability of the blind to discriminate and localize sound. The same should be determined for other sensory modalities. However, good information is very difficult to secure. Data available from the New York State Commission for the Blind indicate that there has been a steady increase in the percentage of clients 65 years and over who are on their register for the blind. For instance, in 1956 the percentage was 45,[2] in 1960 it was 48 percent,[3] and steadily increasing. That this trend is likely to continue appears to be evident from register incidence data available for New York. In 1959, 5 percent[4] of all new additions to the register were 65 years and over. In 1960, ne year later, this figure had risen to 50 percent.[3]

Obviously, the percent of the population 65 years and over, as well as its ate of increase, varies by state. For instance, in 1961 Kansas, a rural state compared o New York, showed that 58 percent[4] of clients on the blindness register were 65 years nd over.

According to Rev. Carroll,[5] audiograms made of groups of blind and sighted ubjects showed that the former are subject to the same area of hearing loss as the atter. Moreover, a certain few causes of blindness also affect the hearing to such n extent that the subject who is blind may also be hard of hearing, if not deaf. In his category are certain of the meningial diseases, and apparently some of the amilial forms of retinitis pigmentosa. In this connection, there may be quoted a tudy by Landau and Feinmesser,[6] of a group of 22 patients with retinitis pigmentosa, ged 11 to 56 years of age. Fourteen of these 22 patients showed impairment of hearing hen tested audiometrically; 9 had nerve deafness bilateral, 2 mixed deafness bilateral, 2 conduction deafness bilateral and one was totally deaf. The authors indicate that deafness is one of the most frequent degenerative processes associated with retinitis pigmentosa, the frequency being variously reported as between 2 and 43 percent of those tested. The differences in these percentages are explained as being due perhaps to diversity of methods employed to measure hearing or to different criteria in evaluating the degree of impairment.

A study of war-blinded veterans in a post-war setting,[7] published in 1958 by the Veterans Administration, showed that, based on interviews by social workers of 1949 blind veterans, 577 or 30 percent, had hearing difficulties. Of the 1949 blind veterans, 855 or 44 percent, had no useful sight, while 1094 or 56 percent, had partial sight. Interestingly enough, of those without useful sight 33 percent had hearing difficulties compared to 26 percent of those with partial sight. Apparently where the vision loss is more serious, there is apt to be an associated hearing loss. However, it should be remembered that veterans constitute a selected group.

Rev. Carroll[5] indicates that even a slight hearing loss may be serious to a blind person in view of the fact that so much dependence is placed on this sense. A hearing loss in such a person may interfere with spoken communication. A slight loss in one or both ears may even more seriously affect the ability to orient oneself and one's mobility, by interfering with the power to localize sounds. Certainly any hearing loss cuts down on the total amount of sound received and thus limits the occasions on which it is possible to use the power of localization. A hearing loss in one ear may be as serious as in both; any inequality in hearing power between the two ears can distort judgment of direction of sound, and so interfere with orientation. Rev. Carroll indicates that similar hearing losses are much more disabling to the blind person than to the sighted. Even a loss that is less than disabling can be quite important.

There are many limitations with respect to the help that a hearing aid can provide to a blind person.[5] No hearing aid reproduces the whole normal range of sound. A sound that may be useful for social purposes may prove to be quite inadequate for travel purposes and vice versa. A hearing aid may help in one type of sound perception but be of very little help in other types. The very reception of auditory cues is diminished by the mere insertion of an instrument in the ear. This may be very important for the blind person. Directional cues may be distorted by a hearing aid. In short, hearing aids do not provide the answer to the difficulties of blind persons with even slight hearing losses.

The congenitally blind may suffer from additional congenital defects, including defects of the other sensory systems, some of which may not be detected for a number of years after birth. According to Warkany,[8] the separation of prenatal and postnatal factors responsible for deafness is admittedly difficult. Trauma or infection may be superimposed on developmental defects of the ear and be considered the cause of the hearing defect. As deafness due to infections becomes rarer, congenital anomalies of the ear assume increased importance.

Since blindness in the aged often results from, or is associated with, certain chronic diseases, such as diabetes, this fact alone would surely pose some problems for the blind. It has been found that diabetes often causes sensory loss, including that of finer cutaneous discrimination. Much blindness results from diabetic retinopathy. In many such people certain tactual areas are made insensitive by the progress of the diabetes itself. As a result, the blind diabetic may have a poorer sense of touch than many of the general population in his own age group. This would surely pose problems in the learning of braille and in the use of certain mobility aids.

Since individuals use each of their senses to add to the information brought by the others and to test and validate that information, it becomes obvious that the mere fact of being blind must surely add to the handicaps of other modalities.

As pointed out before, the risk of having an associated impairment in hearing or touch may be increased in the blind for certain causes of blindness, in congenital blindness, and in those 65 years and over. Furthermore, due to the aging process and its effect on perception and other central nervous system functions, the ability to utilize devices effectively may be impaired in those 65 years or over. If there is accepted as fact the probabilities of such increased risk, is it possible to come up with some idea of the magnitude of the known blind population that might have difficulties with devices for the reasons mentioned above?

To approach this magnitude even crudely one must depend on statistical data available from registers of some of the states. It must be kept in mind, however, that data from state to state, or even data in the same state from time to time, may not be comparable. This may be due to variations in the definitions of blindness, either from state to state or service to service. There may be variations in the classification of causes of blindness used, and finally the matter of chance variations from year to year. If one has recourse to prevalence data from a register, it must be continually borne in mind that the question of updating the register either continuously or on a periodic basis is very important since clients die or move out of state or show improvement in their vision sufficiently great so that they are no longer considered legally blind. Sometimes knowledge of such changes are not easily secured or, if secured, the registers may not reflect such changes promptly.

With respect to incidence data, it is certain that there must be a considerable number of undiagnosed cases of blindness in any state. Also where cases are diagnosed, they may not be reported promptly or at all. Furthermore, the onset of the condition may be years prior to registration or even to diagnosis.

With all these limitations in mind one may observe that at the end of 1961 Kansas register[4] prevalence data show that 58 percent of persons registered were individuals 65 years and over, 2 percent were individuals with retinitis pigmentosa and under age 65 years, 1 percent were individuals with diabetic retinopathy and under 65 years of age, and 6 percent were blind as a result of prenatal conditions and under 65 years of age. Thus, if one adds together all such individuals who might conceivably present problems in the use of devices, according to the present state of knowledge, one comes up with the imposing total of 67 percent of the total register. When attention is turned to register incidence and recourse is had to the New York State register[3] for the year 1960, individuals aged 65 years and over constituted 50 percent of new cases, individuals with retinitis pigmentosa under age 65, 2 percent, with diabetic retinopathy under 65 years, 10 percent, and with blindness due to prenatal conditions under 65 years, 14 percent. Thus, the total of these several conditions as possible sources of difficulty in the use of sensory devices among new cases comes to 76 percent.

In addition to information on the minimum sensitivity required for effective use of devices using the specific modalities, data are needed from samples of congenital and adventitious blind, stratified by age and sex, giving sensory data by modality and changes in sensitivity over time.

More must be known about the learning capacities by age of the blind, with and without other sensory handicaps. According to Dr. Kleemaier,[9] there is a loss of reaction speed in the senium, whether the individual be sighted or blind. The older individual's performance is considerably less consistent, more erratic than that of younger adults. In part, this may be due to uncontrollable lapses in attention as well as to progressive perceptual deficits. The loss of speed is a phenomenon basic to mental events and one intimately involved in aging of the nervous system. Little or no work in this connection has been done with aged blind individuals. The ability of such individuals to perceive and integrate sounds into letters and letters into words must be studied. In similar fashion, their ability to perceive and integrate tactile stimuli of different intensities, positions and durations must be investigated. One must distinguish sensory acuity from sensory efficiency. This has been well publicized in the field of vision by Hoover.[10] In the hearing and touch modalities, such differentiation has not been as well noted.

It is known that the sexes differ in survivorship. What is not known is whether this difference also reflects a difference in "survivorship" by sex of the remaining sensory channels among the blind.

The Office of Vocational Rehabilitation is working toward the adoption by states of a routine, uniform test of hearing for all blind individuals applying for vocational rehabilitation services. This would be of great value, at least in this one segment of the blind population, in supplying information so badly needed for efficient planning of rehabilitation programs and of sensory device development. The possibilities of studies of individual differences in sensitivity, as related to other characteristics, would be very inviting with such data.

3. Finally, there are needed data derived from controlled studies of the use of selected devices by a panel of the blind studied longitudinally. This panel should consist of blind persons satisfying sensitivity requirements for the effective use of the devices tested. There may be practical problems in setting up or in observing such a panel over time, but these problems need solution with the same resolve and urgency that are given to problems on the drawing board or in the laboratory.

Such a study would allow the determination of problems in adjustment to, and continued use of, sensory devices. It would reveal difficulties in training the blind and in their operation of the devices. Tests would need to be devised to measure proficiency in using the devices. Additionally, questionnaires with respect to attitudes and motivation toward use of devices would have to be developed.

A longitudinal study would permit the determination of those specific demographic, physical, personality and other psychological characteristics that make for successful use of the devices under consideration. It may well be that successful cane travellers are also successful travellers with ultrasonic guidance aids or other devices. If so, such a fact will be well worth establishing. The development from such a study of valid selection techniques to allow early screening is greatly to be desired.

Another great advantage that would accrue to a well-planned longitudinal study of a panel of blind individuals might be derived from the fact that heretofore unavailable information on incidence of disease and impairments over time in such a population would become available. This would entail, of course, periodic medical examinations. The facts relating to association of diseases and impairments and their value with respect to rehabilitation and other programs cannot be overestimated.

The laboratory is not the outside world. A mobility or communication system must be useful outside of the laboratory as well as in it. The laboratory should be able to provide approximations to real life situations in the preliminary evaluations of the devices. The devices must, however, be tested in life situations by the blind who will be living with the devices and with the situations. While it is essential that a device be first looked into from the viewpoint of engineering ease and feasability, the ultimate consumer will make the final decision.

The blind or blindfolded college student hardly represents the typical blind individual. Differences in age, perceptual ability, learning speed, and motivation are quite apparent. The motivation exhibited by a young student cannot be compared with that of an aged blind person who may fear danger of the unknown more than the isolation imposed upon him by his sightlessness.

It is no doubt true that much thought has been given by others previously to some of the considerations that have been mentioned. Such considerations may make it possible to avoid ending up with devices in search of consumers. Such an ending would serve neither the blind nor the ingenious scientists and engineers whose devices are either a reality or still a dream on the drawing board.

REFERENCES

1. Goldstein, H. and Goldberg, I.D. The Model Reporting Area for Blindness Statistics. The Sight-Saving Review, 32:84-91, 1962.
2. Commission for the Blind of the New York State Department of Social Welfare. Summary of 1959 Program Activities and Census of the Blind in New York State as of December 31, 1959. Mimeographed.
3. Commission for the Blind of the New York State Department of Social Welfare. Summary of 1960 Program Activities and Census of the Blind in New York State as of December 31, 1960. Mimeographed.
4. Unpublished tabulations for 1961, Services for the Blind, Kansas State Department of Social Welfare.
5. Carroll, Rev. T.J. Blindness, What It Is, What It Does, and How to Live with It. Boston, Mass.: Little, Brown & Co., 1961, 382 pp.
6. Landau, J. and Feinmesser, M. Audiometric and vestibular examinations in retinitis pigmentosa. British Journal of Ophthalmology, 40:40-44, 1956.
7. Department of Medicine and Surgery, U.S. Veterans Administration. War Blinded Veterans in a Postwar Setting. Washington, D.C.: Veterans Administration, 1958, 260 pp.
8. Warkany, J. Congenital malformations and pediatrics. Pediatrics, 19:725-733, 1957.
9. Kleemaier, R.W. Psychological development in the later years: increment or decrement. Prepared for use in connection with a conference for physicians entitled, "Gerontology, Medicine's Responsibility to Older People," held January 13-15, 1955, sponsored by University of Michigan and Michigan State Medical Society.
10. Hoover, Richard E. Visual efficiency as a criterion of service needs. Proc. 36th Convention, American Association of Workers for the Blind, 1962, Cleveland, Ohio.

VII

COMPARISON OF THREE INFORMATION-GATHERING STRATEGIES IN A POPULATION STUDY OF SOCIO-MEDICAL VARIABLES

by

Joseph R. Hochstim
California State Department of Public Health

EDITOR'S NOTE:

This paper was presented at the Annual Meeting of the American Statistical Association, Minneapolis, Minnesota, September 8, 1962, and was published in the 1962 PROCEEDINGS OF THE SOCIAL STATISTICS SECTION, American Statistical Association. Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

The Human Population Laboratory is an epidemiologic study whose primary interest is in learning the distribution of disease in a community and examining the relationships between disease and those social, psychological, and environmental factors which we loosely call "way-of-life."

Since the development of disease, particularly chronic disease, is a long-term process, a longitudinal study design, where repeated interviews are taken with the same individuals over time, appears to be appropriate for the Human Population Laboratory.

Obviously, it is costly to conduct personal interviews with a reasonably large sample of the population repeatedly, particularly if one follows all or a sample of the migrants wherever they go. This led us to look into less costly methods of information-gathering, primarily telephone interviews and mail questionnaires, or to some combination of methods which might lower costs without reducing quality.

Our first step was to comb the literature to discover what studies had been made on the comparative merits of personal interviews, telephone interviews, and mail questionnaires. We went through the major publications in survey research, applied psychology, sociology, statistics, and marketing. In many of the journals we made a complete search back to 1948.

In general, much has been written about the various methods of data collection, but attempts to compare different data collection methods have been very few. Also, what limited information is available does not fit our particular situation--developing a longitudinal study, in a compact geographic area, and in a position to exercise rigorous controls over the quality of any method chosen.

We therefore found it necessary to conduct our own study. This report represents the results of this study. Our objective was to compare three strategies of information-gathering--mail, telephone, and personal interviewing used in certain combinations--in terms of rate of return, the completeness of the returns, and cost. In addition, we aimed to investigate comparability of the results obtained by the three strategies.

The site selected for the Human Population Laboratory is Alameda County, in the San Francisco Bay area. The county has a population of more than 900,000--mainly urban and suburban, like most of California. The population is heterogeneous with respect to occupation, socio-economic class, race and other factors possibly related to disease occurrence. The area is small enough to allow data collection with a minimum of travel expense, while its proximity to the State Department of Public Health permits a maximum of supervision.

A short description of the sample design is necessary here because this design affected the analysis of the study.

An area probability sample of Alameda County, California, was drawn based on 1960 Census data. A multistage design was used. The only 1960 Census statistics available at the time of sampling were Census enumeration districts; so we decided to use these as our primary sampling units. The county was stratified by geography and the enumeration districts were selected with probability proportionate to size. Each enumeration district in the sample was subdivided into secondary units--blocks or, in rural areas, quasi blocks. Two blocks were chosen from each sample enumeration district, again with probability proportionate to size. Within each block, a cluster of six households was drawn from a random start. Altogether, 175 enumeration districts, including 350 blocks and about 2,100 households, were thus selected. This sample, supplemented by a sample of new construction, conversions, and demolitions undertaken since the 1960 Census, yielded a total of 2,148 housing units.

The 2,148 sample households were then enumerated. Enumeration involved a listing of all household members by sex, age, and relation to head, as well as certain housing and other information. As you see in Table 1, the enumeration was successfully completed in 92 percent of the selected households; or in 97 percent of the occupied housing units.

Altogether 1,973 housing units were enumerated in groups of six housing units per block. These housing units were next subdivided into two samples. All those units which fell on the even numbered lines of the block listing sheets became Sample A, the subject of our present discussion. The remaining households were reserved for a replication of the study design, but using a different subject matter.

The sample for the present study was divided into three subsamples, each a representative sample of the total county. Out of the total of 350 blocks, 50 were selected systematically for personal interviews, three households per block. In the other 300 blocks, three households per block also were taken--one assigned at random to the telephone strategy, the other two assigned to the mail strategy. Obviously, cost factors determined the disproportionate numbers assigned to the three strategies.

For all three strategies we did everything possible to achieve a high rate of return. We used all the prestige of the Department and the fact that we are promoting public health. Each household received an advance notice of its selection for the study, in the form of a letter from the chief of the Human Population Laboratory printed on Department of Public Health stationery, personalized as far as possible, and handsigned. Extreme care was exercised at every stage of the study to induce a sense of participation in the respondent.

In all three strategies every member of the household 17 years and over was eligible for the study. Identical questions were used throughout, the topics being demographic, familial, behavioral, and medical.

Let me describe each of the three strategies. In the mail strategy, each member of the household 17 years of age and over was sent a separate questionnaire, with an accompanying letter. A second mailing, again with an accompanying letter, was sent to those who did not return the first questionnaire; and, if necessary, a third--this by

Table 1

RATE OF RETURN OF HOUSEHOLD ENUMERATION

SAMPLE STATUS OF HOUSING UNITS	HOUSING UNITS	
	Number	Percent
Total Housing Units	2,148	100
Enumeration completed	1,973	92
Enumeration not completed	175	8
Reason not completed		
Refusal	33	2
Not at home	20	1
Other biasing reasons[1]	10	a
Vacant	90	4
Other nonbiasing reasons[2]	22	1
Total Effective Sample (Excluding "Vacant" and "Other nonbiasing")	2,036	
Number and percent of effective sample completed	1,973	97

[1] Includes households containing persons who were too ill to be interviewed or who were senile.

[2] Includes persons ruled out of the sample by definition e.g., students living on campus and military personnel on military bases.

[a] Less than .5 percent.

certified mail with the request that the addressee sign a return receipt. The post-office also was asked to report a new address in case the person had moved.

Those who did not respond to the three mailings were then called upon, either by telephone or in person. Callbacks were made to obtain as high a return rate as possible within the limits of the budget. So much, at present, for the mail strategy.

In the second strategy, the primary aim was to conduct the interview by telephone. However, some people do not have a telephone. In order to keep the three samples comparable, the telephone sample included its proper share of nontelephone subscribers; otherwise it would have represented a higher socio-economic group. Those households drawn for the telephone strategy which did not have a telephone were handled like the mail sample.

The third strategy employed personal interviews, with callbacks where necessary.

The overall rate of return from all three strategies combined was 90 percent (Table 2). Nonreturns were made up of 7 percent refusals and 3 percent not-at-home and unable to locate.

Table 2

RATE OF RETURN OF DATA COLLECTION

SAMPLE STATUS OF PERSONS	PERSONS	
	Number	Percent
Total Adults[1] in Housing Units	1,984	100
Interviews or questionnaires obtained	1,779	90
Not obtained	205	10
Reasons not obtained		
Refused	135	7
Not at home	15	1
Unable to locate (moved and left no forwarding address)	33	1
Other reasons	22	1

[1] Persons 17 years old and over.

Looking at the three strategies separately (Table 3), we find that a completed questionnaire or interview was obtained from 88 percent of the mail strategy sample; 91 percent of the telephone strategy sample was completed, as was 93 percent of the personal interview strategy. Thus, as far as rate of return is concerned, all three strategies proved satisfactory.

In each of the three strategies the great bulk of the assignment was completed by the method originally selected. For example, the 88 percent obtained in the mail strategy was made up of 81 percent returned by mail, the other 7 percent divided about evenly into telephone and personal interviews. The 91 percent return from the telephone strategy included 72 percent completed by telephone, 14 percent by mail, and 5 percent in person.

Our next concern was the completeness of the questionnaires. Even though the mail strategy yielded a satisfactory rate of return, the questionnaires themselves might have a disproportionately high rate of unanswered questions. Over the telephone as well as in the personal interview, the interviewer can encourage responses; this sort of prodding is not possible in the mail questionnaire. Therefore, it was expected that the proportion of unanswered questions in the mail strategy might be higher than in the other two strategies. As it turned out, this expectation was justified, but the non-response to individual questions was so low--seldom going over 5 percent even in the mail strategy--that it did not present a problem.

I should comment here that the figures on rate of completeness for the mail strategy include a few edited questionnaires. If a questionnaire was returned which had, say, a whole page left blank, it was assigned to an interviewer who telephoned the respondent to obtain the answers to the unanswered questions. Thus, the rate of

Table 3

RATE OF RETURN BY STRATEGY AND METHOD OF COMPLETION

METHOD OF COMPLETION	STRATEGY		
	Mail	Telephone	Personal
Number of adults in households	1,109	571	304
Number of interviews obtained	977	518	284
	Percent		
Percent interviews obtained	88	91	93
Obtained by			
Original method	81	72	90
Other methods	7	19	3
Mail	x	14	3
Telephone	4	x	-
Personal	3	5	x

Table 4

SUMMARY OF NONRESPONSE TO SIXTY-ONE QUESTIONNAIRE ITEMS BY STRATEGY

PERCENT "NO ANSWER"	NUMBER OF ITEMS NOT ANSWERED		
	Strategy		
	Mail	Telephone	Personal
0.0	20	25	30
0.1-0.9	14	13	14
1.0-1.9	10	14	5
2.0-2.9	4	3	4
3.0-3.9	2	3	2
4.0-4.9	5	3	4
5.0 or more	6	-	2
Average percent "No Answer"	1.9	0.9	1.0

completion of mail questionnaires is the rate of respondents' answers plus some subsequent prodding in the few cases where there were gross omissions.

Coming now to the question of costs: There are a great many expenditures that enter into the conduct of a survey--administration, planning, sampling, questionnaire construction, testing, etc. We are concerned here only with the cost of interviewing, on the assumption that most other expenses will not vary greatly with the strategy employed. However, there are questions of just what charges to include in interviewing, and what fractions of certain costs to assign to each strategy.

You will remember that we conducted a household enumeration before doing the actual interviewing. This was necessary in order to get names and addresses for the telephone and mail strategies. One could take the position that enumeration and interviewing might have been conducted simultaneously in the personal strategy and therefore none of this enumeration cost should be assigned to this strategy. However, this view is not quite realistic because all members of the household 17 years and over were to be interviewed, and even where a respondent was available on the enumeration trip, additional visits were often necessary to interview the other eligible household members. In fact, in many cases the enumerator found no one at home and simply took name and address for subsequent telephone calls to complete the enumeration for those households. Consequently, it is not unreasonable to charge at least a fraction of the enumeration to the personal strategy.

Another expense involves selection, training, and supervision of interviewers. Such costs are quite substantial in the personal interview strategy, a little less so in the telephone strategy, and minor in the mail strategy. How much of this interviewer supervision should be charged to each strategy?

We computed per interview costs on a number of bases, ranging from charging personal strategy with none of the enumeration to charging various fractions, and from dividing interviewer training and supervision costs equally among the three strategies to assigning them heavily to personal and telephone strategies. Depending on what assumptions we made on these issues, we came up with the following comparisons: Telephone strategy interviews cost from 10 percent to 20 percent more than the mail strategy returns and personal strategy interviews cost from two to two-and-a-half times as much as mail.

I want to draw a broad band of caution around these comparisons. These figures apply only to this particular study, and even here we are not sure how good our cost accounting was. With a different rate paid to interviewers, or with a different length of questionnaire, or with any difference in procedure--for example, no certified letter in the mail strategy--cost ratios would change, perhaps considerably. All we can say is that, not unexpectedly, the personal interview strategy cost substantially more than either of the other two.

So far we have shown that in terms of return and in terms of completeness, the three strategies were quite comparable and that in terms of cost, the mail and telephone strategies were more efficient than the personal interview strategy.

The next item to investigate is a comparison of the findings from the three strategies. Let us look first at those data for which comparisons with outside sources are available, i.e., Census. Does any one of the three strategies appear to have a marked advantage over the other?

Not all statisticians agree on the usefulness of comparisons between sample data and population data. While some are unimpressed, others think that such comparisons are a realistic way of assessing the representativeness of a sample. Without taking sides on this issue, I will report the comparisons we made on a series of items obtained in the Human Population Laboratory which were also reported in the 1960 Census.

When the returns from the individual strategies are compared with one another and with Census data, we find (Table 5):

1. In most cases results from the three strategies are in good agreement with each other and with Census, and
2. None of the three strategies is consistently closest to the Census on all items compared.

Interestingly, the mail and the telephone strategies show just as close relationships to Census as does the personal strategy. In fact, the largest difference--though not statistically significant--appeared in the personal strategy. The important point, however, is that all three strategies are close to Census and to one another.

Our next effort involves a comparison of the substantive findings obtained by the three strategies. I won't go here into the details of computation of the standard errors except to say that I have been using a technique pretty much like the one Leslie Kish presented in his article on "Confidence Intervals for Clustered Samples," in the April 1957 issue of the American Sociological Review. This technique is not unlike the one Jerome Cornfield described in the study on "Health and Medical Care in New York City." In essence, these techniques take cognizance of the fact that we are dealing with a cluster sample instead of a simple random sample.

Generally speaking, the three strategies drew similar responses. In the great majority of findings, the differences observed are not large enough to be statistically significant. There are, however, a number of questions and a number of items on which statistically significant differences did appear. By chance alone, we would expect that in 5 percent of the comparisons, a statistically significant difference would occur. In fact, we observed such differences on 6 percent of the items.

If we look at the questions where significant differences are found, and if we make some attempt to arrange them systematically and classify them in order to seek a rationale for what may have happened, certain patterns emerge.

First, we find that about one-third of all the differences appear in one series of six questions. This was our first attempt to develop an index of physical activity and I am afraid we were not successful.

Second, some of the interstrategy differences seem to arise from the need for special instructions or explanations. For example, in recording occupation of the respondent, interviewers can be given detailed instruction as to how occupation will be coded and should be recorded. The fact that in the mail strategy 7 percent of the answers were uncodable, while only 2 percent each for the telephone and personal strategies were uncodable, documents this speculation. The same point holds for recording "industry" and for some other items too.

Third, there are situations where ideas about acceptable responses give the advantage to one strategy over another. Herb Hyman and our chairman, here, in their standard work on "Interviewing in Social Research," have dwelt on the importance of interviewer expectations in survey research. Respondents, too, have ideas of what is expected or is acceptable. If somebody asks me, or any one of you, "How do you feel?" we almost automatically answer, "Fine," even if we don't feel very well. Similarly, when our interviewers asked respondents how they would generally rate their health--excellent, good, fair, or poor--the automatic response tended to be "excellent." However, asked to put down a check mark on a questionnaire, the response tended to be less off-the-cuff than in the more social situation.

Comparing findings on health rating for the three strategies, you will observe in Table 6 that the proportion saying "excellent" is much higher in the personal strategy, and the proportion saying "fair" is higher in the mail strategy. I would

Table 5

COMPARISON BETWEEN U.S. CENSUS 1960 AND HUMAN POPULATION LABORATORY

DEMOGRAPHIC VARIABLE	U.S. CENSUS 1960[a]	HUMAN POPULATION STUDY 1961		
		Strategy		
		Mail	Telephone	Personal
Total Persons 17 Years and Over	595,556	977	518	284
	PERCENT			
Sex				
Male	47	48	46	45
Female	53	52	54	55
Age				
Less than 25	13	10	13	13
25-34	20	19	24	22
35-44	22	23	22	22
45-54	18	19	15	19
55-64	13	13	13	13
65-74	9	9	8	5
75 and over	5	6	4	5
Not reported		1	1	0
Race				
White	86	86	86	78
Negro	11	10	11	16
Other races	3	4	3	6
Nativity				
Native born	91	88	90	90
Foreign born	9	11	10	10
Not reported		1	b	b
Marital Status				
Married	71	75	75	68
Widowed	9	7	8	9
Divorced	5	5	4	4
Separated	2	2	3	4
Never married	13	11	10	14
Employment Status				
In civilian labor force	61	61	59	63
Employed	57	57	54	58
Looking for work	4	4	5	5
Not in labor force	39	39	41	37
Occupation[1]				
Professional and managerial	23	21	21	21
Clerical and sales	25	29	30	31
Craftsmen	14	13	16	13
Operatives and laborers	20	20	19	18
Service workers	11	10	12	15
Uncodable	7	7	2	2
Industry[1]				
Agriculture	1	2	3	2
Construction	6	6	7	5
Manufacturing	22	21	22	19
Transportation, utilities, communication	8	8	9	12
Trades	18	16	16	21
Services	31	26	28	27
Public administration	8	8	11	10
Industry not reported	6	13	4	4

[1] Census figures refer to employed persons, Human Population Laboratory Study excludes housewives and students.

[a] Adjusted to exclude students and military personnel not in the Human Population Laboratory Study.

[b] Less than 0.5 percent.

Table 6

RESPONDENTS' HEALTH RATING BY STRATEGY

	STRATEGY		
	Mail	Telephone	Personal
Total Persons	977	518	284
	Percent		
Total Percent	100	100	100
Health Ratings			
Excellent	30	37	44
Good	51	51	45
Fair	17	10	10
Poor	2	2	1

hypothesize that in this case, the mail strategy may come closer to reflecting the respondents' true state. What is operating here is probably not so much a desire to deceive as the impulsive face-to-face response compared to the more considered reply to a printed question.

Another example: In our culture, drinking alcoholic beverages, particularly by women, is not quite acceptable middle class behavior. If we look at the findings on drinking wine, beer, and hard liquor (Table 7) we notice that some 8 percent to 11 percent more women tell the interviewer that they never drink than make this response on

Table 7

FREQUENCY OF DRINKING ALCOHOLIC BEVERAGES WOMEN RESPONDENTS BY STRATEGY

	STRATEGY		
	Mail	Telephone	Personal
Total Women	507	282	157
	Percent		
Total Percent	100	100	100
Women saying they			
Never drink wine	46	44	55
Never drink beer	51	49	59
Never drink whiskey or liquor	36	34	47

the impersonal mail questionnaire. This appears to be a case where respondents conceivably may answer more honestly if they are not facing an individual who may be critical of their behavior.

So much for the pattern of differences. Looking now at the magnitude of the differences, we find them not very large. Aside from the physical activity items, the mean of the statistically significant differences between any two strategies is 7 percentage points, and the range is from 4 to 14 points.* Introducing this element of the size of the observed differences brings up the question of statistical in relation to practical significance. Often a difference, even though statistically significant, has little substantive importance.

To sum up: We all know that in any interview study, however conducted, some respondents are easier to find than others, and that the hard-to-get respondents are very costly. Because we have been aware that certain types of people do not respond to mail questionnaires or are not available by telephone, we tend to conduct entire studies by personal interview, even when the information may be obtainable by other techniques.

What I have reported here is a study of three strategies of information gathering. In two, we made an effort to obtain the easy-to-get interviews in the less costly ways, at the same time identifying the hard-to-get respondents for follow-up by the more expensive techniques. The third strategy was based on the personal interview in order to gain comparative data.

As I reported:

First--Rate of return was satisfactory for all three strategies--

RATE OF RETURN BY STRATEGY

Mail strategy	88%
Telephone strategy	91%
Personal interview	93%

Second--We did get the bulk of our interviews by the method originally assigned--

RATE OF RETURN

Strategy by Method of Completion

METHOD OF COMPLETION	STRATEGY		
	Mail	Telephone	Personal
	Percent		
Total	100	100	100
Mail	92	15	3
Telephone	4	80	-
Personal	4	5	97

---

*On the physical activity items, the corresponding figures are 11 percentage points for the mean and 5 to 19 points for the range.

Third--Rate of questionnaire completeness also was satisfactory for all three strategies--

AVERAGE PERCENT "NO ANSWER"
PER QUESTIONNAIRE ITEM

Mail strategy	1.9
Telephone strategy	0.9
Personal interview strategy	1.0

Fourth--Interviewing costs were about two to two-and-a-half times as high for the mail strategy. In our case, differences in cost between mail and telephone strategies were small, 10 percent to 20 percent.

COST RATIOS OF DATA COLLECTION
FOR THE THREE STRATEGIES

Per Questionnaire Cost of Mail Strategy
Equals 100

STRATEGY	RATIO TO MAIL STRATEGY
Telephone strategy	110-120
Personal interview strategy	190-240

Finally--So far as substantive findings go, there were some interstrategy differences. On a couple of items, interviewer instructions were important and on these the personal and telephone strategies were probably superior. And in a few cases answers to an interviewer appeared less considered than responses to the mail questionnaire. On balance, however, the returns from the three strategies were quite comparable and it appears that on most items the strategies could have been used interchangeably.

Before I begin to sound as though I am advocating the use of the mail or telephone strategy, I should say that I am aware of certain limiting factors. One I have touched on: A public health department, seeking information which presumably would benefit many people, may have an aura that induced an unusual rate of mail and telephone cooperation. Obviously, a lower return would have changed cost comparisons considerably.*

---

*Of course, some may take issue with my favorable interpretation of the auspices of a public health department. Arnold Simmel, in an article in the August 1962 issue of the Journal of Public Health, speculates on a possible unfavorable image of public health as contributing to the defeat of a number of referenda on fluoridation. So, take your choice.

Another limiting factor is that certain kinds of inquiries simply cannot be made by mail or telephone--because they are too complicated, because they involve tests of knowledge, because question sequence is important, because of the sensitivity of the subject, and so forth.

What we are searching for, of course, is a way that can be used in certain situations to save costs, particularly where follow-ups in a longitudinal study are involved, and where the problem of respondent mobility looms large.

There is much analysis still to be done on these data. Additional investigations are also being made. You may remember that in discussing the sample design, I mentioned that we put aside half of the households enumerated, those listed on the odd-numbered lines of the enumeration sheets. We have just completed in these households a survey which replicates the methodological study I have discussed, but with a different subject matter. A good many questions, however, are identical in the two studies. Therefore, with a sample using households on the very same blocks, we have a two-pronged effort here: a complete replication on some issues and also new information on a very sensitive subject matter.

Since these data are in the processing stage, no compairsons can be made at this point in time. It is hoped that by replications of studies of this type, it will be possible to build up a body of knowledge giving us information as to if, and under what conditions and with what safeguards, mail and/or telephone interviews, supplemented by personal follow-ups for the hard-to-get cases, are practicable.

VIII

REVIEW AND SUMMARY OF READING MACHINES

by

Franklin S. Cooper
Haskins Laboratories, Inc.
New York, New York

EDITOR'S NOTE:

This paper was read at the International Congress on Technology and Blindness, 1962, and will be reprinted in the Proceedings of that Congress.

In these three sessions on reading machines for the blind, we have heard about a very diverse set of topics. They have ranged from extremely sophisticated engineering to equally sophisticated psychology; they have dealt with a wide time-span in the development of devices--all the way from rigorous testing of devices-in-being to speculations about how the improved devices of the future may some day be designed. Perhaps you have your own check list of speakers and topics. This is mine: Four papers dealt primarily with applications and devices, ranging from the very specific devices discussed by Coffey and Beddoes to the applications of pneumatic logic and tactile displays described by Bliss, and the use of "spelled speech" demonstrated by Metfessel. Four more papers were concerned with the general principles of reading machines and how their outputs could be matched to the receiving capabilities of the user. Clowes and Mauch talked mostly about machines that operate at the letter-by-letter level, while Selfridge stressed the differences between vision and audition in processing patterned information, and Kennedy specialized the general case to a requirement for natural speech in the output of a high-performance reading machine. Then there were three papers on optical character recognition. Rabinow and Kazmierczak summarized developments and prospects in the United States and in Europe; Scharff urged a coordinated design philosophy in any developments undertaken in this field.

Such a diversity of topics defies a straightforward summary. I shall not attempt the impossible, nor shall I impose on you an inadequate review of topics that our speakers have just presented, clearly and at length. I shall try, instead, to relate these contributions to the broad problem of devising reading machines for the blind and to possible approaches to a solution.

The Reading Machine Problem in General Terms.

Let me start, even though it may seem unnecessary, by restating the major requirements for a reading machine for the blind. Briefly, the blind man wishes to read a wide range of the same books, magazines, and typewritten materials that his sighted friends are reading; he would like to have a personal device, reasonably portable and inexpensive, for use whenever he wants it, as well as access to materials in libraries; finally, he would like the device to talk to him, for he has no more time than anyone else for the drudgery of learning a machine language and listening to a letter-by-letter rendition of the printed page.

There are some inherent contradictions in these objectives: a machine that can read rapidly in plain English is unlikely to be portable and cheap enough for personal use; indeed, designs based on reasonable extrapolations of present technology are sure to be large and expensive, even for use in libraries. Similarly, it is unlikely that the performance of Optophone-like devices can be improved by an order of magnitude through the discovery of some ingenious, non-speech code. We may, at least for the near future, be faced with inescapable compromises between the performance of the machine and its complexity; however, we dare not compromise with its capability to read ordinary printed materials. These points may appear obvious, and I would not have stressed them, except that one still encounters--as, indeed, we have at these sessions--recurring proposals for machines that require specially prepared input materials, and for research programs to reexplore coding possibilities that have been examined almost every decade since Fournier d'Albe invented the Optophone half a century ago.

So much for the problem; what kinds of reading machines can we envision? Three main lines of development are indicated in Figure 1. They all start with some means for scanning the printed page and converting its black-and-white letter shapes into electrically coded signals. The diagram deals rather casually with this process, though, in fact, it is a rather complex operation and one that will be expensive to automate; however, the development of suitable document handling and scanning devices should be fairly straightforward, so perhaps I may be excused for devoting most of the diagram to those areas of signal processing where research as well as development are still required.

Direct Translator Types of Reading Machines.

Of the various types of reading machines, the direct translator (top line of Figure 1) has received by far the most attention. The operating principle common to a large variety of such devices as the Optophone, Battelle Aural Reading Device, and Argyle is that the shape of the letter on the printed page is converted into an acoustic shape, or pattern, for presentation to the listener. The acoustic code that results from this coversion will necessarily be an arbitrary one, but it should be possible for a listener to learn the rather limited number of sounds that correspond to letters and punctuation marks.

Such devices are appealing in their simplicity--and appalling in their performance. One might not object to learning an arbitrary code if he could reasonably expect to become proficient in its use. This has not proved possible with any of the existing schemes and there are, in fact, good reasons for supposing that inherent limitations (in human perception rather than in the devices) will continue to frustrate inventors of this class of reading machine.

This seems a rather grim prospect; if one contemplates reading his favorite magazine at something between, say, 10 and 30 words per minute, it is grim indeed. But for some tasks, such as reading personal correspondence, locating and identifying documents, finding telephone numbers, and the like, the rate of reading is very much less important than the ability to read at all. We owe a debt of gratitude, I believe, to Dr. Eugene Murphy for clearly realizing the importance of this simple virtue of Optophone-like devices, and for having persevered in the effort to develop one that would be small enough and cheap enough to be readily available to the individual when he needs it. It is in this light that we should assess the very considerable success reported here in the development and testing of the Battelle device.

Reading Machines That Talk.

Why not require the reading machine to speak plain English--or whatever language the user himself speaks? There would be no problem then of learning an alien and cumbersome acoustic code, or of being unable to read rapidly. This would be an obvious and elegant solution--but also a complex and expensive one. It may, nevertheless, be the answer we should seek.

Character recognition is one of the necessary steps in making the printed page talk, as I have indicated in the bottom line of Figure 1. We have heard several papers on optical character recognizers at this Congress; hence, I need to say very little about the box labelled "Character Recognizer," except to note that I have introduced a somewhat arbitrary sub-division of its internal operations because I wished to have two different kinds of outputs available for the later discussion of the center line of the figure, involving sound generators. In a logical sense, at least, character recognition proceeds by the successive steps of isolating certain properties (features) of the letter shapes and of identifying the particular letter, by looking for combinations of these properties. The two steps may not always be distinct, as when character recognition is carried out by direct optical superposition. For our present purpose, however, we are concerned only with the final output of the recognizer (i.e., the input to the speech generator), which is a string of discrete electrical signals that represent letter identities.

The most important of all the things we have been told about character recognizers is, I think, Rabinow's statement that we could have, by today's techniques, an optical character recognizer that would meet the blind person's need--and have it for about $5,000-10,000. To be sure, Rabinow may be a little optimistic as to price and delivery, but the point remains that it is realistic even today to plan for reading machines that include character recognizers.

The kind of recognizer that Rabinow referred to was not the standard, high-speed type designed for business applications, but a much simpler machine based on the same technology. He implied that the time is ripe for those working on aids for the blind to proceed forthwith to the development of simplified optical character recognizers. It is a tempting prospect, especially for some of us who are gadgeteers at heart, but I wonder whether this is the best place to put our effort. I think not, and for several reasons: first, the technology is still being developed very rapidly for business purposes and with business funds; second, we are not ready to use a character recognizer and it will be several years before we have workable answers to those parts of the problem that are unique to reading machines; finally, there is at least a reasonable question about the economics of simple, cheap recognizers for reading machines versus large, expensive ones that can work very much faster. We often assume, as both Rabinow and Mauch seem to have done, that a library-type reading machine (including its optical character recognizer) will serve the blind reader directly, i.e., that the machine will be obliged to work in real time, and so could not use (and need not have) the high-speed capabilities of business-type machines. In fact, it may be cheaper to use the fast, expensive machine to prepare tape recordings that will be used off-line by the blind reader. This would of course obviate the need for any special development of the type that Rabinow suggested. It might be possible, nevertheless, to find a simple recognition scheme that would be inherently suited to real-time operation and that would deserve development primarily for application in reading machines. I take it that this is what Mauch has in mind.

I have not counselled against devoting effort to optical character recognizers because they seem uninteresting or unnecessary--far from it--but because other problems are at least as important and are not likely to be solved with other people's money.

Speech generation from input information about the letters on the printed page is such a problem; indeed, it may well be the key problem in research on reading machines. There are a variety of ways in which speech might be produced, as is suggested by the diagram (Figure 1) inside the box labelled "Speech Generator." The details of this block are shown in Figure 2, though even here the entries are merely illustrative, not exhaustive. You will notice that there are two essentially different kinds of output signal, either synthetic speech, or speech compiled from recordings of bits and pieces of actual utterances. Both types of output were discussed and demonstrated in Kennedy's paper. His synthetic speech came from a system represented by the two boxes at the

AUDIBLE OUTPUTS FOR READING MACHINES

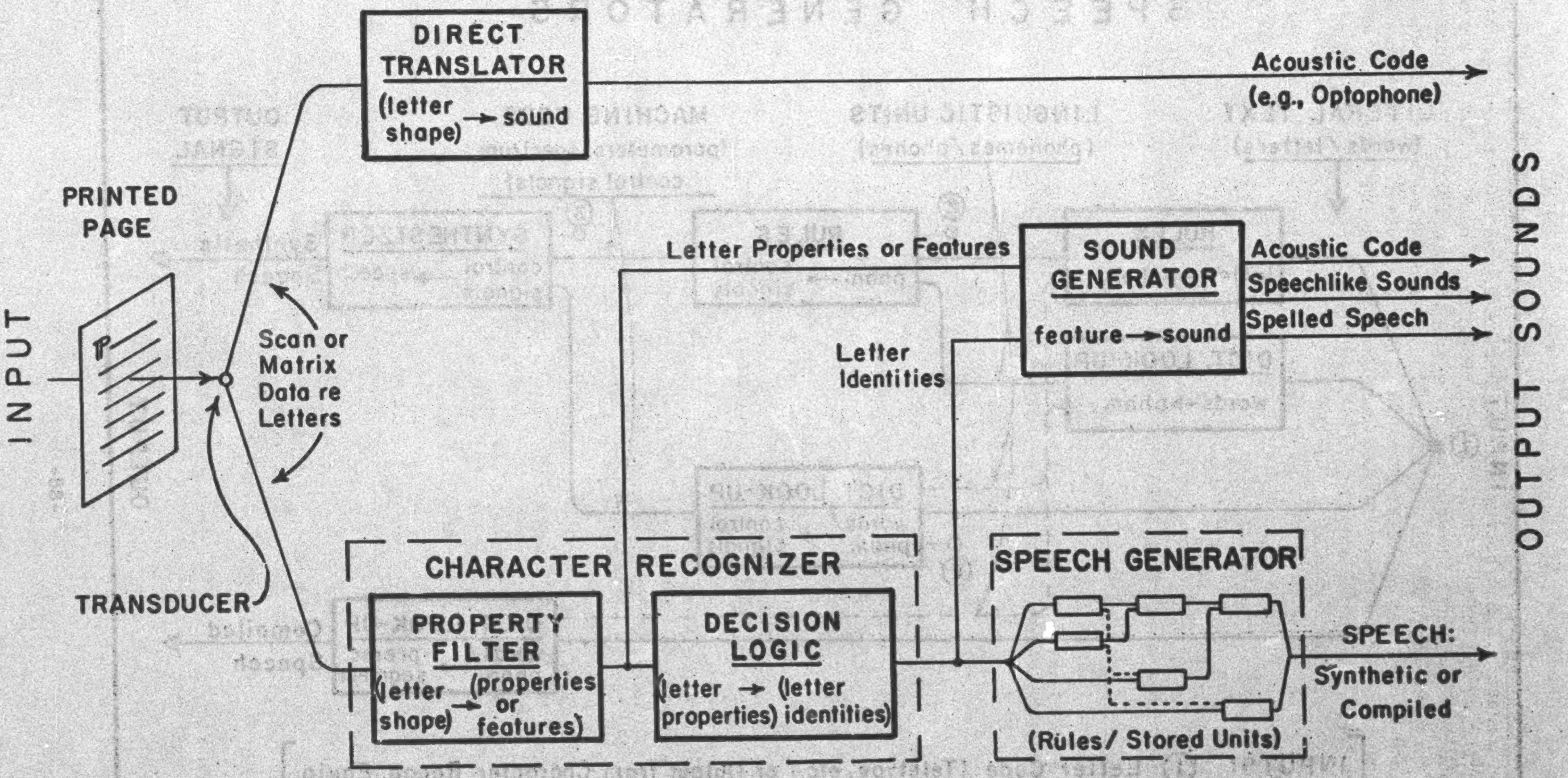

INPUT
PRINTED PAGE
TRANSDUCER
Scan or Matrix Data re Letters
DIRECT TRANSLATOR
(letter shape) → sound
Acoustic Code
(e.g., Optophone)
CHARACTER RECOGNIZER
PROPERTY FILTER
(letter shape) → (properties or features)
DECISION LOGIC
(letter properties) → (letter identities)
Letter Properties or Features
Letter Identities
SOUND GENERATOR
feature → sound
Acoustic Code
Speechlike Sounds
Spelled Speech
SPEECH GENERATOR
(Rules/ Stored Units)
SPEECH:
Synthetic or Compiled
OUTPUT SOUNDS

Figure 1

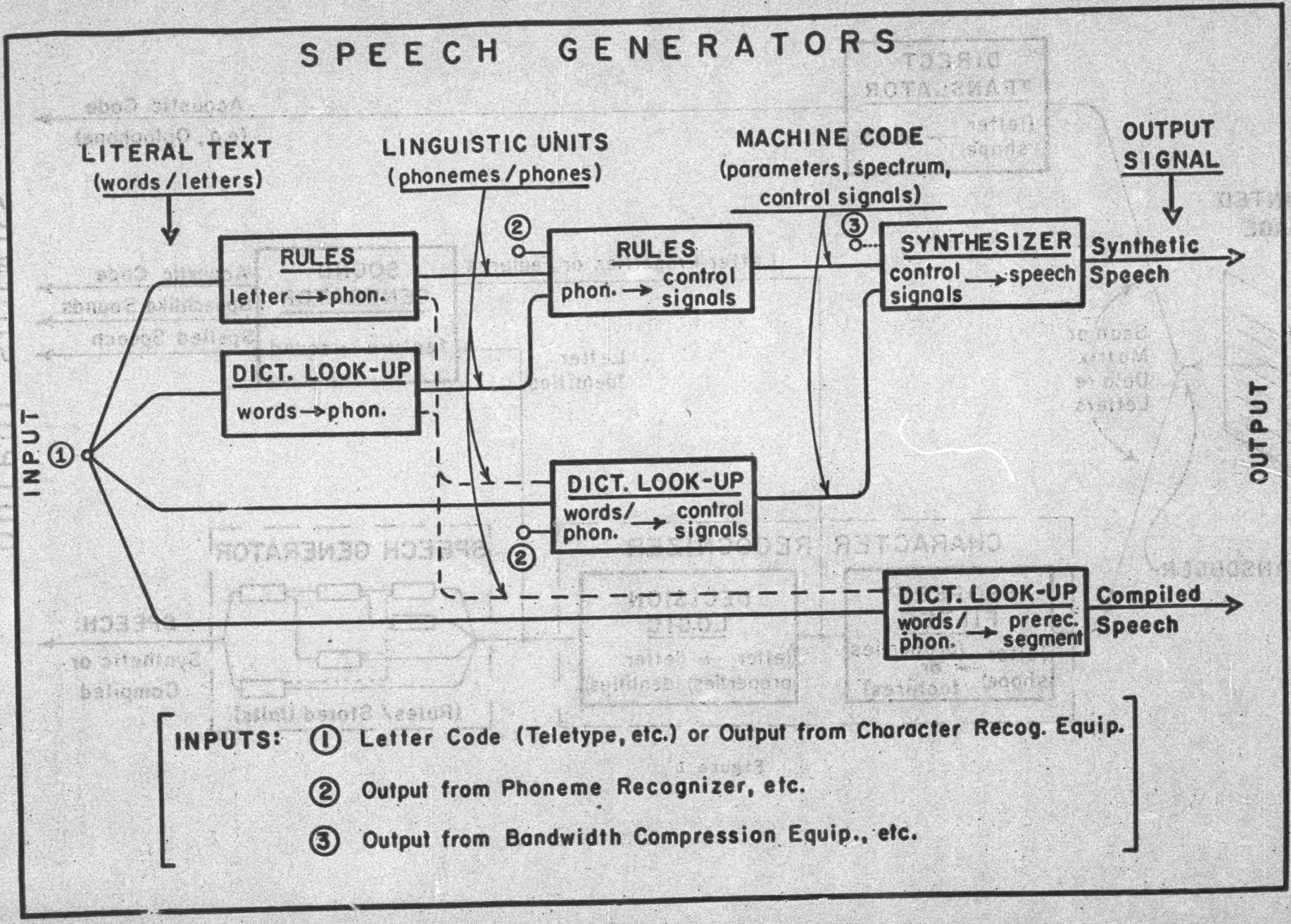

SPEECH GENERATORS
LITERAL TEXT
(words / letters)
LINGUISTIC UNITS
(phonemes / phones)
MACHINE CODE
(parameters, spectrum, control signals)
OUTPUT SIGNAL
INPUT
①
RULES
letter → phon.
DICT. LOOK-UP
words → phon.
②
RULES
phon. → control signals
DICT. LOOK-UP
words/phon. → control signals
②
③
SYNTHESIZER
control signals → speech
Synthetic Speech
DICT. LOOK-UP
words/phon. → prerec. segment
Compiled Speech
OUTPUT
INPUTS: ① Letter Code (Teletype, etc.) or Output from Character Recog. Equip.
② Output from Phoneme Recognizer, etc.
③ Output from Bandwidth Compression Equip., etc.

Figure 2

right of the upper line of Figure 2, i.e., those labelled "Rules: phonemes → control signals" and "Synthesizer." The compiled speech was from a dictionary of recorded words, and so corresponds to the fourth (bottom) level of the diagram.

It is rather interesting to compare the trade-off between instrumental complexity and design sophistication that is implied by each of the different paths through this diagram; some of the paths (shown dotted) represent methods that are possible but not, perhaps, very useful. In general, the top line implies the least machinery but the most research; the bottom line, the reverse. The middle levels substitute increasingly extensive dictionaries for the logical operations implied by "Rules."

The differences among paths are not only those of design sophistication versus hardware, however, for there are inherent differences also in the acceptability of synthetic and compiled speech. There will not, I think, be any question of intelligibility even at rather high reading rates, but rather one of naturalness and listening effort. Synthetic speech can almost certainly flow more smoothly than compiled speech and, if it is synthesized by rules (top level), there will be no need to interrupt the continuous flow of speech in order to spell out words that do not appear in the dictionary unit. But there are disadvantages too: speech synthesized by rules will have some odd pronunciations reflecting the vagaries of English spelling and the minor inadequacies of converting linguistic units into control signals for a synthesizer; it will, in short, be machine speech. Compiled speech will sound quite human and each word will be pronounced pleasantly and accurately, though the pronunciation may not quite fit the context and there may be some rather odd intonations. The major difficulty, however, will be the frequent interruptions for spelling. This is a point to which I shall return in a moment. The intermediate procedures, involving dictionary searches for word-to-phoneme or word-to-control-signal entries, may in fact be the lines along which an optimum solution is to be found. It has been demonstrated,* for example, that stored control signals can produce synthetic speech so similar to natural speech as to be almost indistinguishable from it. Thus, by a suitable choice of intermediate procedures, we may attain the advantages of synthetic speech with the naturalness of compiled speech, though at a price that combines the most expensive features of both procedures, i.e., much research and a large memory.

How large must these memories be and how serious is the spelling problem? Clearly these are related questions, since spelling should become more and more infrequent as the dictionary becomes larger and larger. Some rough estimates may interest you: assuming ordinary magazine text and a recorded vocabulary of about 6000 words, one will expect to spell about 1 word in 20 (5 percent); for a vocabulary of 15-20,000 words, the spelling rate should be down to about 1 percent; the vocabulary required to duplicate a desk-size collegiate dictionary is about 60,000 words, or to match Webster's Unabridged, about 600,000. The difficulty, of course, is that word frequencies lie on a very long-tailed distribution. The practical problem has the further complication that one does not know how much spelling the user will tolerate, and there is no way to find out without running extensive tests with substantial amounts of compiled speech and with sizeable groups of blind users.

There are some things one might do to alleviate the situation, though they complicate the machinery. For example, a great many words occur in pairs that differ only in an added s or es to form the plural. It seems a waste of memory space to store both forms, so one might devise some way to look for the plural suffix, then use the recording for the singular form and add a brief buzzy sound. Another useful procedure may be to use specialized vocabularies to supplement the general vocabulary. Thus, in reading an article on music, for example, the specialized vocabulary would contain the names of musical instruments and other terms which would almost certainly not occur in the first ten or twenty thousand words of a general-purpose vocabulary.

---

*Such a demonstration was given by Dr. Gunnar Fant at the Sixty-first Meeting of the Acoustical Society of America, Philadelphia, May 1961.

Let us suppose that the use of these special methods will make it possible to hold the spelling rate to acceptable levels with a general vocabulary of only 10-20,000 words. How much machinery does this imply? Probably we should consider digital storage, not because it is necessarily best suited to speech but because all the large random-access memories developed for business purposes are digital devices. We can use the spelling of the word as its address and, for practical purposes, ignore the storage space that this requires. If we use pulse code modulation to record the speech--the obvious, direct way--we shall require several hundred million bits of storage for a 10,000 word vocabulary. This implies a rather big device; some of the newer, large-scale disc memories would just suffice.

The speech information could be coded more compactly, perhaps by a factor of 30 to 50, if the storage were in the form of control signals to operate a synthesizer (next line to the bottom in Figure 2). Somewhat less storage would be needed, and we might be able to generate really excellent speech, if the control signals were to operate a synthesizer that is an analog of the human vocal tract. Such a synthesizer would have the "physiological" constraints built into it, so that fewer external controls would be needed. The difficulty is that nobody yet knows quite how to generate these control signals, though this problem is being worked on at both the Massachusetts Institute of Technology and the Bell Telephone Laboratories.

It might even be possible, in line with Kennedy's comments about the articulatory basis for speech perception, eventually to obtain still simpler control signals in terms of "motor commands" that drive the "musculature" of a vocal tract analog. But this is 10 to 20 years away, since we have neither the knowledge of how to generate the control signals nor of how to build the synthesizer.

Perhaps we should reexamine the possibility of storing the speech or control signals in analog form, rather than digital. If storage area (magnetic or optical) is taken as a criterion, then indeed analog storage has definite advantages. For example, about the same area of magnetic recording surface would be needed to store a spoken vocabulary by ordinary (direct) magnetic recording as would be needed for the same vocabulary in the highly processed form of digital control signals such as we have been discussing. It is tempting to conclude that this would justify a program for the development of a random-access memory especially suited to speech storage--a challenging problem but not, I think, our proper business at this time, since we can get by with the digital equipment that is already in being.

Intermediate Solutions to the Reading Machine Problem.

We have now considered the two extremes; let us turn to possible devices that are neither so limited in performance as the direct translators nor so complex and expensive as the generators of synthetic or compiled speech. We shall find an odd mixture of quick compromises, long-term possibilities, and beckoning mirages. The intermediate types of device indicated on the center line of Figure 1 have the distinguishing properties (1) that the output is not quite speech and (2) that the input, although it may require something less than full recognition of the printed letters, is nevertheless categorical, and so implies that some kind of decision or recognition process has been applied to the non-categorical information supplied by the scanner. The hope, of course, is that comparatively simple operations can be made to yield an adequately useful output.

Mauch has described briefly a device that used letter features to generate sound units of word length rather than letter length. Clearly, this was a step in the right direction, since one of the difficulties with the acoustic code from direct translators is that the signals do not blend and flow as they do in the words of speech. Might it not be possible to merge the information about successive letters to obtain syllable-like or word-like acoustic outputs, and do it without losing the distinctions between different printed words or incurring the complexities of generating natural speech?

Some of the features of letter shapes (projection above or below the line, curvature, diagonal stroke, and the like) should be comparatively easy to identify by machine and so could provide a distinctive code for the word. It would then remain only to generate distinctive "word sounds." Perhaps arbitrary acoustic codes of this kind can be found that will be easily learned and also be identifiable at rapid reading rates, as Clowes and others have suggested. There has been very little work on this possibility and one can only guess at the answer.

Another possibility, much more attractive to those of us who have worked on speech perception, is to start with the same information about letter features but to generate acoustic codes that will be speech-like in the sense that they are readily pronounceable, i.e., they could be mimicked. There is good theory and good evidence for supposing that such a speech-like code would prove to be quite efficient and would not be very difficult to learn. Indeed, it should be less difficult than to master a foreign language, since the code would at least retain familiar meanings and grammar. The only difficulty with this otherwise attractive possibility is that no one has yet seen how to instrument it by means that are markedly simpler (either in extracting the necessary letter properties or in generating the speech-like sounds) than would be required to go all the way to letter identification and the generation of natural speech.

Still another intermediate possibility was described for us by Metfessel. He has used a very rapid form of spelling as the acoustic output. This should be easier to implement than any of the speech generators we have discussed thus far and, in fact, Mauch has developed a mechanical unit that is ideally suited to the purpose. However, a "spelled speech" device would have two severe disadvantages: it would require the full services of an optical character recognizer to provide its input, and its output, though simply instrumented, would be only marginally acceptable. For these reasons, the method seems likely to find application only as an interim stage in the development of speech generating systems, and also, perhaps, as an inexpensive way to generate an audible output from punched paper tapes that are already available as a by-product from the printing industry.

It might seem from the discussion thus far that all the possibilities shown on the center line of Figure 1 are, for one reason or another, not very promising. This is not quite correct, because it is only here that we can hope to find the ultimate device which will give good performance and yet remain within the size and cost limits for a personal reading machine. It does not follow, however, that this is the area in which current research should be centered. It is quite likely, indeed, that the design sophistication needed to develop a good intermediate device will be far beyond that required for a library-type machine that talks plain English. Consider, as a parallel, today's portable transistor radio. It seems much simpler than the super-heterodyne receiver of the 1920's with its many vacuum tubes and separate tuning controls. The apparent simplicity is deceptive, for it really reflects far more sophistication in components and design than anything imagined in the twenties. Similarly, an intermediate device may someday be built, using cheap and apparently simple hardware to make a feature analysis and produce speech-like sounds, all in a very compact little machine. But we will not know how to design this kind of machine for some years yet.

In Conclusion.

Perhaps I can summarize these remarks, and some of the points made in the earlier papers, under a pair of topics: the requirements that a reading machine should meet, and practical objectives for current research.

As to requirements, we can say flatly that a reading machine must read ordinary type. Ideally, it should also be cheap and portable, permit fast reading, and talk plain English or something that is very easy to learn.

In a practical sense, not all these objectives can be met, and we must be prepared to accept compromise solutions for quite some time. One of these compromise solutions will be a personal-type device (such as the Battelle Aural Reading Device) that leaves much to be desired in performance, but is nevertheless usable where reading speed is not a major consideration. Another will be that of a reading machine for use in libraries or centers where tapes are recorded for distribution. This will inevitably be a complex and expensive machine, but it should produce natural speech of quite acceptable quality. In addition, there may be intermediate devices of one kind or another that will fill special needs, though they are not likely to be both simple enough for personal use and effective enough for general use; however, the reading machine of the future may well be an intermediate-type device, but one that attains its simplicity of hardware by a combination of sophisticated design and the use of a speech-like output.

Clearly, there is much research to be done--so much that it behooves us to sift out the real problems from the pseudo-problems and, even then, to give careful attention to priorities.

Among the real problems is the practical one of getting a good direct translator into use. This means choosing one specific device, building a number of models for field trials, and working out training methods. The Battelle Aural Reading Device is the logical choice, for it is good enough in an absolute sense and far closer to practical realization than any other competitive device.

Another research area, important for the development of a high-performance library-type device, is the output problem, i.e., how to generate acceptable speech. We do not, I think, need to be much concerned just now with the development of optical character recognizers and large random-access memories, though they are essential components. It seems fair to assume that by the time the output problem is solved--that is, in another two or three years--such devices will be available, having been developed primarily for business applications of electronic data processing. The marriage of these devices with a speech generator to provide a high-performance, library-type reading machine should be a fairly simple ceremony.

A third area on which research ought now to be proceeding is the development of tactile devices or methods for generating tactile text. This aspect of the reading machine problem--inescapable for text that contains diagrams, maps, or formulae--has had less attention here than it deserves.

Finally, there will be a gap in the development schedule between the Battelle-type device and the high-performance reading machine for library use. Anything that can be done to provide intermediate devices for the interim period should be carefully considered.

Are there areas of low priority? I realize that this is a delicate question, but when resources are so limited it is all the more important to avoid unprofitable enterprises. One of these would seem to be the effort to evolve a better output for direct translation devices. I would even label this a pseudo-problem, on two counts: first, there is a great deal of evidence that improvements, if any, will be marginal; second, if a device such as the Battelle machine is carried to the point that people can and do use it, then it makes very little sense to duplicate the development costs just to produce a different device of about the same capabilities.

Another problem to which I would assign a rather low priority is the engineering development of optical character recognizers or large random-access memories. These are not unimportant problems, but they will be solved by other people for other purposes by the time we need the devices for reading machine applications.

I should like to end these remarks with a brief reminiscence and a gratuitous prediction. In the mid-1940's, the Committee on Sensory Devices sponsored some research on reading machines for the blind. It did a careful survey of the prior art and listened attentively to suggestions for new developments. Near the end of its active life, the Committee considered a project for the construction of a device to recognize type-written characters and generate the corresponding letter sounds. This idea, even though proposed by a world-famous scientist high in one of our largest electronics companies, seemed almost too visionary to warrant exploration. Today, the idea seems amusingly archaic.

As a prediction, let me say that we will have, within five years or so, at least one major library center in which a reading machine is being used to prepare tape recordings for blind users; further, that the machine will be largely automatic, will provide quite acceptable speech at normal-to-rapid reading rates, and will be so fast that the cost per tape will be quite modest. I hope none of you will accuse me of betting on a sure thing, even though I probably am.

IX

APPARATUS FOR THE BLIND TO BE USED IN READING ORDINARY TYPOGRAPHIC TEXTS

(POLYPHONIC AND TACTILE)

by

M. M. Germanov
Laboratory of Typhlo-technology
Scientific Research Institute of Defectology
Academy of Pedagogical Sciences of the R.S.F.S.R.

EDITOR'S NOTE:

We are indebted to the Battelle Memorial Institute, Columbus, Ohio, for the translation of this article.

The most perfected and spread braille system for the blind, which uses tangible dots for writing and reading purposes, does not fully meet the reading requirements of its users, so that the wealth of world literature is far from being rendered in this relief printing system.

Because of their constantly growing intellectual needs, the blind should acquire the capacity of using the usual literature published for those who are not blind.

For this purpose, the black letter-signs of typography must be transformed by means of a special apparatus into corresponding signs discernible by the analyzing sense organs of the blind.

The idea of creating a photoelectrical apparatus to enable the blind to read the usual print belongs to the talented Russian physician and inventor V.A. Tiurin, who first spoke of it on April 22, 1894, at a meeting of the Russian Technical Society. Models of V.A. Tiurin's apparatus were displayed at the exhibition of the first all-Russian electrical engineering convention.

The process of transforming letter-signs into signals accessible to the blind is divided into three stages connected together and dependent upon one another:

a. The transformation of black letter-signs into electrical signals possessing characteristic marks for each letter
b. The amplification and formation of electrical signals within the ranges necessary to enable the blind to perceive them
c. The excitation of a signal characteristic for each letter and perceptible by the analyzing sense organs active in the blind.

The success of the method depends of course upon whether the signaling process can be based on a psychophysiological factor.

The history of the devices used for reading shows that V.A. Tiurin as well as his successors had foreseen in them the presence of a signaler, acting in a complex or divisible way on auditory, tactile or motor analyzing sense organs of the blind reader.

The special physiological features of the olfaction and taste receptors preclude the possibility of using them in deciphering the signals of devices used in reading.

The analytico-synthetic capacities of the auditory analyzing organ enabling man, especially, to discern vocal signaling, that is speech--entirely different by its acoustic structure and complexity--reveal wide possibilities for the blind of using special devices in reading usual texts familiar to the non-blind. These devices are based on the transformation of each sign into a phonic signal.

Phonic signaling in reading devices can be of two types:

a. Signaling the letter to be read, by a signal corresponding to the sounding of this letter in human speech
b. Signaling by means of a conventional sound signal whose structure and component are characteristic for each letter of the alphabet.

In an effort to free the blind from the help of a non-blind reader, replacing the latter by an automatic device and dispensing the blind with the necessity to learn any conventional code, some authors conceived the idea of creating "speaking machines." The high complexity of such devices, however, requiring qualified maintenance, has so far failed to guarantee the transformation of a text into a coherent human speech with the intonation emission of accentuated vowels and signs of punctuation.

Conventional phonic signaling can have diverse forms. Monotonous sound signaling is possible. To each letter corresponds a rythmically different signal, or a single-voiced signaling in which a signal with variable frequency characterizes the letter.

Investigations of the laboratory of typhlo-technology of the Scientific Research Institute of Defectology of the Academy of Pedagogical Sciences of the R.S.F.S.R. showed that when conventional sound signaling is chosen, preference must be given to polyphonic signaling in which each sign is a complex signal that can be formed from a series of different audible tones.

The tactile sense organ has very much importance in the life of the blind. In a number of cases the sense of touch replaces for him the lost sense of sight; it permits him, especially to make use of the printed word (relief-dot printing). This explains the effort of a number of authors to transform typographic signs into signals perceptible by the sense of touch. This signaling method proves irreplaceable in the case of the blind-deaf.

There are three types of tactile signaling:

a. Signaling the letter to be read by its enlarged representation in the form of relief dots
b. Signaling by transforming the letters into relief-dot signs corresponding to the letters read by the braille alphabet
c. Signaling by means of a conventional tactile signal whose structure and components is characteristic for each letter of the alphabet.

The first two methods require a complex apparatus and not one of the designs proposed permits a rational solution of the problem involved.

Conventional tactile signaling proved more simple and practically efficient.

Essentially the transformation of typographic signs into signals perceptible by the blind can be explained as follows.

An enlarged representation of the letter is projected on a group of photoelectric cells, optically distributed perpendicularly to a line. This is schematically illustrated in Figure 1.

In the example used there are five photoelectric cells. The images of the letters move relatively to the photoelectric cells uniformly from right to left.

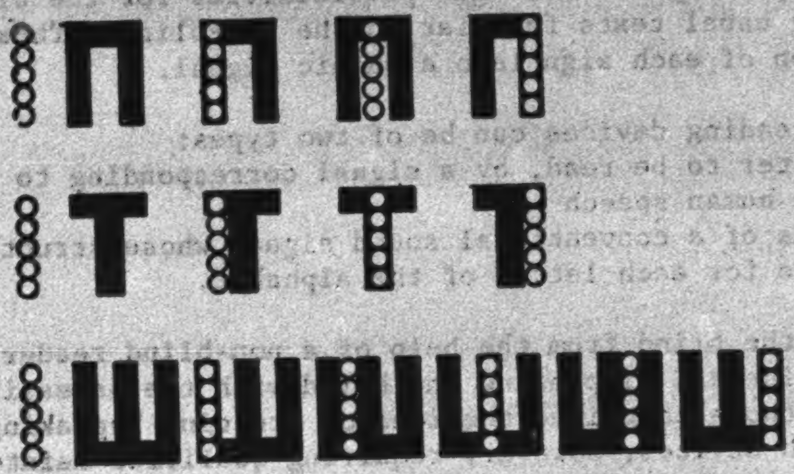


Figure 1. Darkening of the photoelectric cells by images of the letters.

During the time when the intervals between the letters are oriented to all the photoelectric cells, the light rays reflected from these intervals, acting on the photoelectric cells, produce in their circuits dots of a determined size. There is a certain amount of combination in the representation of a letter with the photoelectric cells; according to this amount, the photoelectric cells, partly or entirely, are darkened. During this process, in the different phases of motion of the combination, the darkenings of the photoelectric cells will change according to the configuration of the letter. The dots in the circuits of the photoelectric cells will change according to the illumination and darkening of these cells.

The corresponding amplification and the formation of photoelectric currents guarantee the appearing of sound signals depending on the order of darkening of the photoelectric cells by the image of the letter, that is depending on the configuration of the letter.

Pursuing the idea of V.A. Tiurin, we propose that during the darkening of the first (upper) photoelectric cell the sound "La" appears, during the darkening of the second photoelectric cell the sound "Sol," of the third the sound "Mi," of the fourth the sound "Re," of the fifth the sound "Do." Then when the letter "P" is being read, at first the chord Do-Re-Mi-Sol-La appears, then one sound "La" and again the chord Do-Re-Mi-Sol-La. For the other letters the combinations of the tones developed will be different.

Transforming typographic signs into conventional tactile signals requires a combination with an electron signaling outfit containing, in our examples, five electromechanical systems capable of raising above the surface of the signaling outfit and of lowering five small pins.

Having reserved for the pins the same numeration than in the photoelectric cells, when the letter "P" is being read we obtain first the raise of the types 1, 2, 3, 4, 5, then the types 2, 3, 4, 5 go down and 1 remains in a raised position, then the five pins rise again.

With the help of the finger laid on the ends of the mobile pins, according to the contact combinations, depending upon the contours of the letters it will be possible to differentiate one letter from the other.

A small series of polyphonic devices enabling the blind to read usual typographic texts is developed and will in due time be produced by the typhlo-technical laboratory. In addition to this, the final structural design of an equally manufactured small series of tactile devices reproducing the I.A. Sokolianskii reading method has been obtained. Figures 2 and 3 are photographs of these instruments.

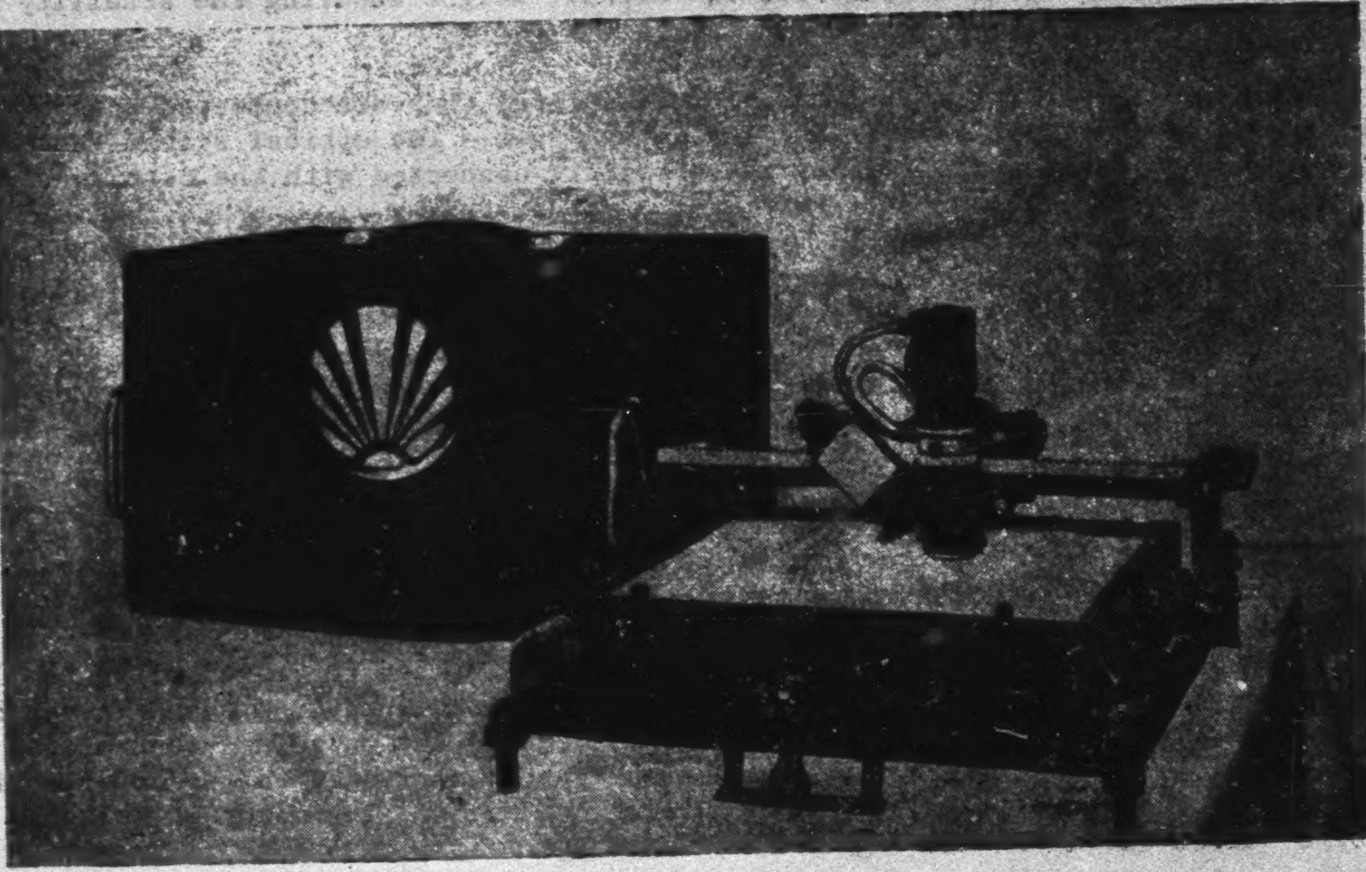


Figure 2. General view of a commercial polyphonic apparatus enabling the blind to read.

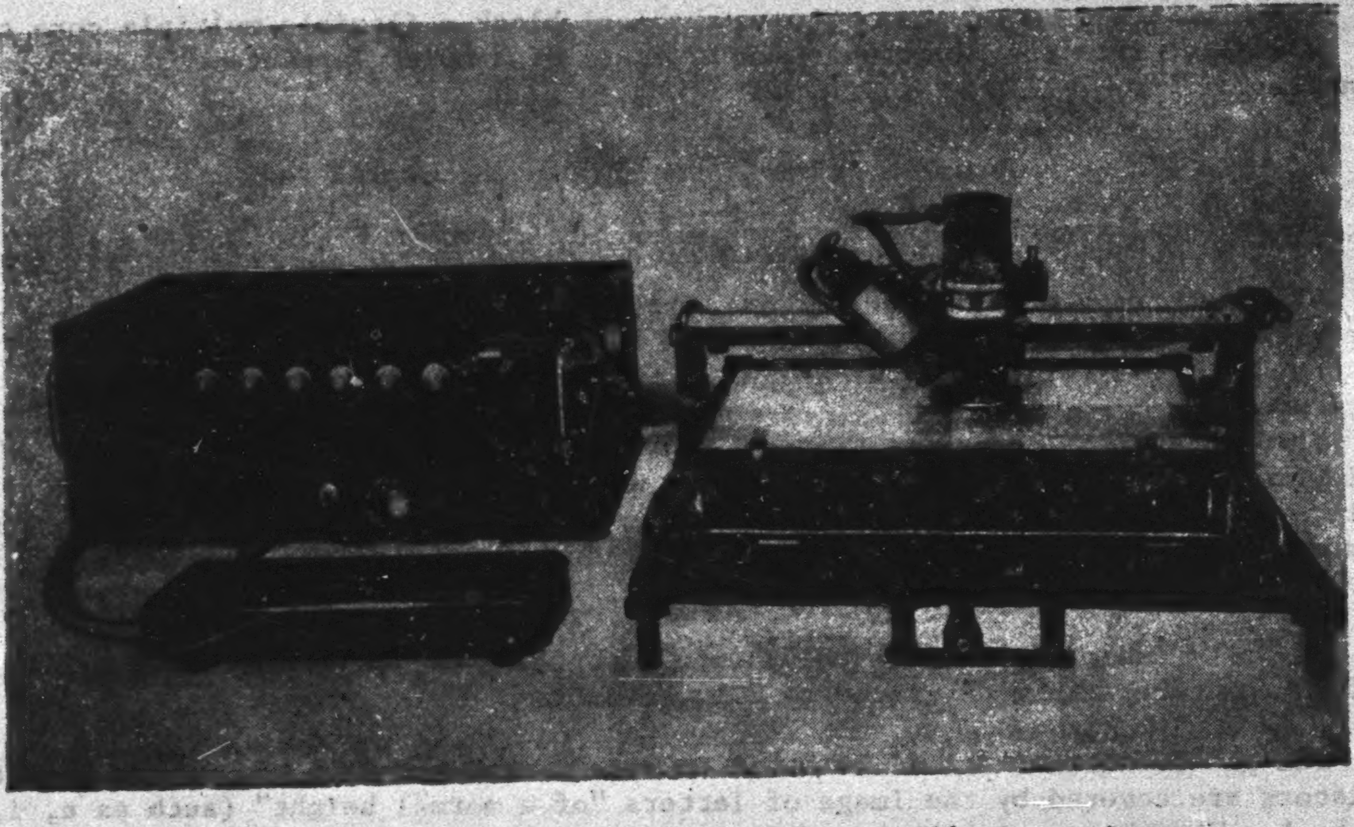


Figure 3. General view of a commercial tactile apparatus enabling the blind to read.

POLYPHONIC APPARATUS

The polyphonic apparatus (see Figure 2) consists of two contiguous blocks: an optico-mechanical, and an electronic part.

The optico-mechanical block is founded on a massive 450 x 380 mm plate. The corners of the plate rest on four feet of variable height ensuring the stability of the block.

Two vertical supports are fastened on the plate; they are connected together by guides along which a mobile part--the carriage--moves. The optical system--the so-called "reading organ" and illuminator--is rigidly connected with the carriage.

A box, where a book 210 x 130 mm in size and 10-15 mm in thickness can be placed, moves toward and away from the reader (ot sebia i na sebia) along the steel guides of the plate thus enabling any line of the book to be brought under the optical system. To hold the book the box is moved to the support, the clamps of the cover glass are rotated and liberate the glass. This glass is raised a little and under it the book is placed on a spring backing. After this, the glass is lowered and fastened with the clamps.

The design provides the possibility to move the box not only perpendicularly to the cylindrical guide, but at any angle with them. This is necessary in order to obtain a parallel line and to direct the motion of the carriage.

The motion of the carriage, causing the "reading organ" to travel along the line from left to right during the reading of the text, is obtained by means of a synchronic motor mounted in the carriage. A cog wheel, mounted on the outgoing arbor of the motor reducer, by rolling on a toothed rack moves the entire carriage, the speed of motion being determined by the diameter of the guiding cog wheel. The motor is switched on or off by a button switch at the right of the carriage.

To return the carriage to its left position the hand releases the guiding cog wheel and the toothed rack. This is obtained by lowering the rack on its pinions.

From the carriage of the optico-mechanical block a flexible multiple core cable can be engaged into the electron block by means of a multiple contact plug-type connector.

THE READING ORGAN

The optical system of the "reading organ" is shown in Figure 4.

The light rays of a source (1) are concentrated by a condenser (2) and through a cover glass (3) are directed on portions of the text. (4) By means of the objective (5) and the prism (6) two letter images completing each other are formed.

Through a slot in the prism, part of the rays pass to a group of photoelectric cells, more exactly photoresistors (7) another part of the rays is projected on a semitransparent screen (8) on which the image of the letter, necessary for control, is formed, the invisible part of the letter corresponding to its part projected at a given moment on the group of photoresistors.

In the "reading organ" the polyphonic instrument possesses eight miniature lead sulfuric photoresistors developed by B.T. Kolomiits.

The photoresistors are distributed in such a way that 3, 4, 5, 6, and 7 photoresistors are covered by the image of letters "of a normal height" (such as e, i, m, n, etc.). The photoresistors 1 and 2 are covered by the elements of the letters over

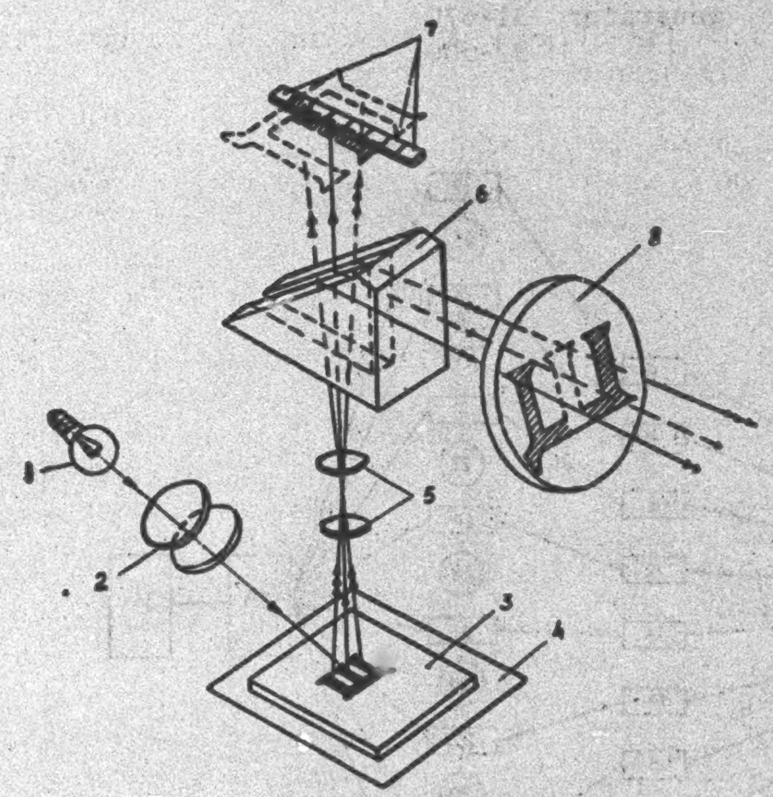


Figure 4.

the lines (b, e, i, f), 8 by the elements under the lines (p, y, f, g).

Thus the signs-letters are distributed in 8 zones, parallel to the line. Obviously the alternation and combination of darkening relatively to the photoresistors will characterize each letter of the alphabet.

The "reading organ" is designed in the form of a cylindrical tubulure inside which are distributed the lenses of the objective, the system to modigy the enlargement, the prism, the diaphragm and the photoresistor compartment. Owing to the system modifying the enlargement it is possible, by rotating an annular rack, to pass from a type of one height to a type of another height within the limits of the points 8, 10, 12 and 16. During this process the distribution of the images of the letter elements on the photoresistors is maintained unchanged.

The light system is connected with the tubulure of the "reading organ" at an angle of 45o. The light source is an automobile bulb.

The Electron Unit

This block is schematically shown in Figure 5.

The electron unit contains 8 autonomous channels working on the point of entry of the power amplifier.

The voltage amplifiers and relay cascades of all the channels are identical.

The frequencies of the sound generators are different and, corresponding with the numeration of the block diagram, they are:

generator 25-3795
" 26-2810
" 27-2100
" 28-1580
" 29-1185
" 30-890

generator 31-670
" 32-500

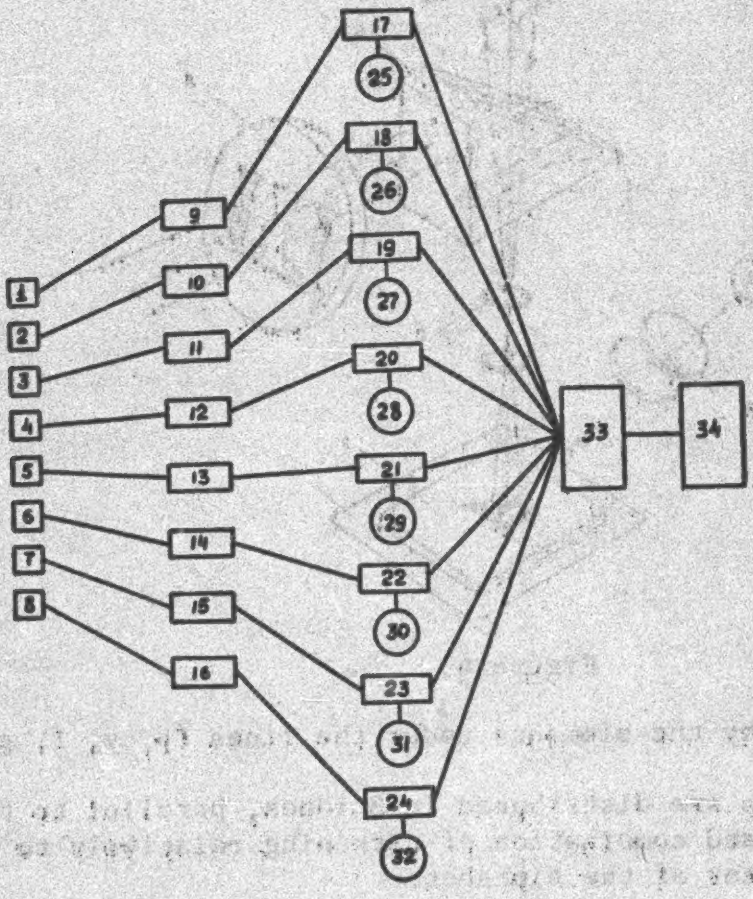

17
25
18
26
9
19
27
1
10
2
11
3
20
4
12
28
33
34
5
13
21
29
6
14
22
7
15
30
8
16
23
31
24
32

Figure 5. Unit diagram of the electron part of the polyphonic apparatus.

1-8. Photoresistors distributed in the reading organ.
9-16. Voltage amplifiers. 17-24. Relay cascades.
25-32. Sound frequency generators. 33. Power amplifier.
34. Sound radiator (signaling element).

The operation of each channel can be explained by the following. See Figure 6.

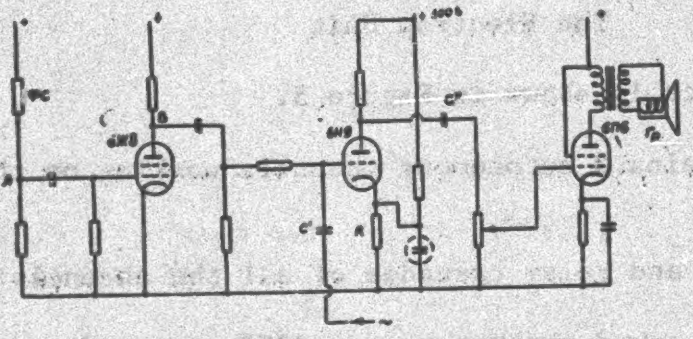


Figure 6. Diagram showing the principle of operation of a channel of the polyphonic apparatus.

Tube 6N9 is cut off by a constant potential on account of the voltage drop on the resistance R. As a result, the signal from the sound generator supplied to the grid of the tube through the condensor C' cannot pass into the anodic circuit of the tube. There is no sound signal.

During the passage of the "reading organ" from the white field of the paper to the black part of the letter, the illumination of the photoresistor, on which the part of the letter is projected, decreases and consequently, its ohmic resistance increases. The voltage at the point A falls, a negative voltage pulse appears, which, after amplifying tube 6Zh8 creates a positive pulse at the point B, unblocking tube 6N9. At this moment the signal from the sound generator can pass into the anodic circuit and through the condensor C reach the grid of tube 6P6, which is a power amplifier of all the channels. A sound signal of a frequency equal to that of the sound generator appears.

At the subsequent moment, during the passage from the black field to the white, a positive impulse appears at the point A and consequently, tube 6N9 is cut off again, and the passage of the signal from the sound generator is interrupted again.

During the change of the illumination of some photoresistors the processes in the channels conjugated with them will occur as shown above, and at the exit a polytonic sound signal will appear.

The electron unit, including a rectifying device for the feeding of the radio tube and of the illumination tube, and an electrodynamic sound emitter, is mounted in a housing 260 x 270 x 450. The sound emitter is arranged on the front panel. Under the emitter there is the volume control of the signal. On the right there is the power switch, on the left-jacks for the switching on of the hand receiver and the loudspeaker switch.

On the rear part of the housing there are the sockets of the plug-type connector, the power voltage switch and the fuse.

The supply of the apparatus is obtained from a DC circuit of 110, 127, 220 V.

The Signal of the Apparatus

As follows from what has been said previously, the structure and the components of the sound signals will be determined by the configuration of the sign over which the "reading organ" passes at a given moment.

A line, perpendicular to the reading line, and overlapping with its image the entire group of photoresistors, will be transformed by the apparatus into a sound chord consisting of 8 frequencies corresponding to all the scanning zones.

When the line is less high and, consequently, when its image does not overlap all the photoresistors, but part of them only, a chord also appears, but consisting of fewer tones.

All other conditions equal, the signals of the letters will depend only on the configuration of the letters.

The heights of the vertical elements of the letters determine the spectral composition of the chord, and their number determines the number of times of the signal ("P"=2 times, shch=3 times). The oblique and irregularly shaped elements of the letters influence the alternation of appearing of the individual signals and of their length.

The diversity of the conventional phonic signals made by the apparatus is determined by the variety of heights, widths, and configurations of the signs of the typographic text.

Knowing the principle of formation of a signal, one may realize that the letter "п", by means of its vertical lines, creates two chords of 2100, 1580, 1185, 890, and 670 cycles, connected together by a tone of about 2100 cycles corresponding to the zone where the horizontal stroke of the letter extends.

The signal of the letter "ш" will differ from the preceding one by the presence not of two but of three chords of the same tones connected with a 670 cycle tone corresponding to the seventh zone passing through the horizontal component of the letter.

The polyphonic apparatus, whose working principle has been explained above, was used in the typhlo-technical laboratory in teaching a group of blind to read an ordinary typographic text. The results of the experiment showed that, on the basis of necessary methods of procedure, the signals of the apparatus and its autonomous operation are accessible to each blind person in possession of a normal hearing organ.

THE TACTILE APPARATUS

The tactile apparatus shown in Figure 3 consists of three connected units: an optico-mechanical unit, an electron unit and an electromechanical unit (the signaling device).

The optico-mechanical unit of the tactile apparatus differs from the optico-mechanical unit of the polyphonic apparatus only by the fact that the number of zones according to which the signs of the texts are decomposed is equal to five.

The photoresistors in the "reading organ" of the tactile apparatus are distributed in such a way that 2, 3, and 4 photoresistors are overlapped by the image of letters of "normal height." Photoresistor 1 is overlapped by the letter elements over the lines, and photoresistor 5 by the letter elements under the lines.

The Electron Unit

A diagram of the electron unit of the tactile apparatus is exhibited in Figure 7.

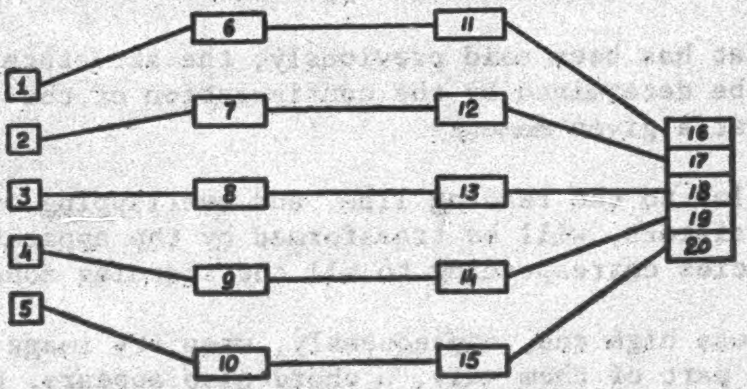


Figure 7. 1-5 Photoresistors distributed in the "reading organ," 6-10 Voltage amplifiers, 11-15 Relay cascades, 16-20 Electromechanical systems of the signaling device.

Thus the electron unit contains 5 identical autonomous channels.

The operation of each channel is explained as follows (see Figure 8).

The tube 6Zh4 is cut off by a constant potential on account of an individual rectifier; the plate current of the tube is equal to 0; there is no current in the magnet winding, its relay armature is not pulled up.

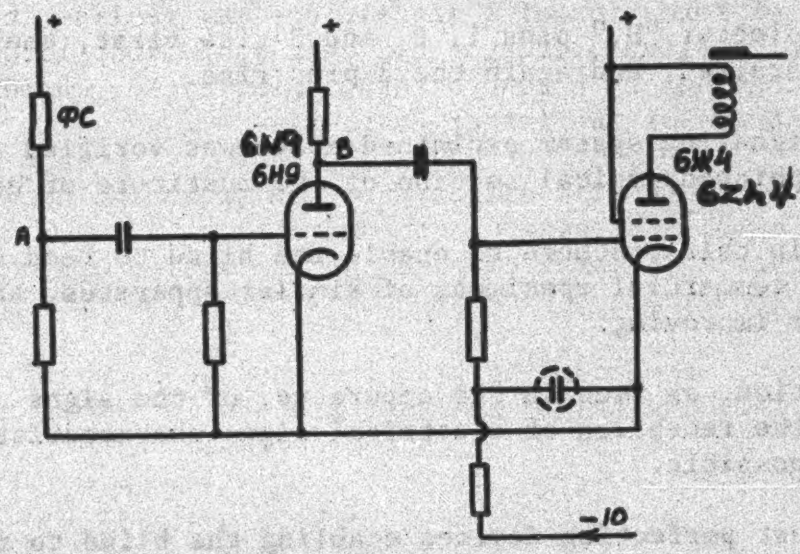


Figure 8. Diagram showing the principle of one channel of the tactile apparatus.

During the passage of the "reading organ" from the white field to the black part of a letter, the illumination of the photoresistor decreases and its ohmic resistance increases. The voltage at the point "A" falls--a negative voltage pulse appears, which after amplifying tube 6N9 creates a positive pulse at the point B, unlocking tube 6Zh4. At this moment in the anode plate of the tube and, consequently, in the magnet winding which is a load, a current appears. The armature of the electromagnet is pulled up and raises above the surface of the signaling device a mobile pin corresponding to a given channel.

During the passage from the black field to the white field a positive pulse appears at point A and, consequently, the tube 6Zh4 is cut off again, the current in the electromagnet wiring is interrupted, the armature is dropped and in consequence the mobile pin is lowered also.

During the change of illumination of some photoresistors the processes in the channels conjugated with these photoresistors will occur as shown previously, and over the surface of the signaling device the corresponding pins are raised and are lowered.

The electron unit together with power rectifiers of the radio tubes and of the illumination tube is placed in a 150 x 200 x 380 mm housing.

The power switch and the pilot lamps of the channels are distributed on the front panel. (The tube behind No. 6 is used only when changing a six-point signaling device.)

On the rear part of the chassis there are the sockets of two plug-type connectors for conjugation purposes with the electron unit of the optico-mechanical unit and of the signaling device, the power voltage switch and the fuse.

The supply of the apparatus is obtained from a DC circuit of 110, 127, and 220 V.

The Signal of the Apparatus

As in the polyphonic apparatus, the structure of the signal depends on the outline of the letter. Pins are distributed on the signaling device such as 1, 2, 3, 4 dots of the braille six-point system. To the first photoresistor corresponds the pin placed at the place of the fourth dot, to the second--of the first dot, to the third--of the second, to the fourth--of the third, and to the fifth--of the sixth.

The pins, corresponding to the fourth and sixth dots, are supposed to show the letter elements over and below the line. The others are for the elements that do not exceed the normal height of the letters.

Thus, when reading the letter "H," pins 1, 2, and 3 rise first, then 1 and 3 are lowered; only 2 remains raised, and again the 3 pins rise.

The usability of the signaling system explained above was verified and demonstrated by fellow-workers of the typhlopedagogical section of the institute of defectology.

The devices described in this brochure to enable the blind to read usual typographic texts are the first commercial specimens of similar apparatus, and of course, will be subjected to further improving.

The system of distribution, as used in the apparatus, of the signs of a text on the elements necessary for the reception of electrical signs characteristic for each letter is not the only one possible.

Considering the fact that perfecting devices enabling the blind to read is a fairly difficult matter, we would appreciate any who would communicate his proposals concerning the problem examined by us. Correspondence in this case must be addressed to:

Typhlotechnical Laboratory of the Institute of Defectology
of the Academy of Pedagogical Sciences of the RSFSR
Kirogradskaia Ulitsa 23-6
Sverdlovsk (District) 12
Soviet Union

REFERENCES

1. V.A. Tiurin, "What can electrical engineering do for the incurable blind," Nauchnoe obozrenue, 1894, No. 24, pp. 737-748.
2. V.A. Tiurin, "A few words about my exhibits," Elektrotekhnicheskii vestnik, 1900, No. 1, pp. 8-10, No. 2, pp. 17-19.
3. V.A. Tiurin, "About my displays at the exhibition during the first All-Russian electrical engineering Convention," Vsemirnoe tekhnicheskoe obozrenie, 1900, No. 8, p. 251.
4. V.A. Tiurin, "Devices enabling the blind to read usual print and handwriting," Transactions of the second All-Russian electrical engineering Convention, 1902, Vol. 3, pp. 64-80.
5. V.S. Sverlov, "Reading and speaking machines," Scientific notes of the pedagogical institute im. Herzen, 1940, pp. 139-156.
6. I.A. Sokolianskii and IU. A. Kulagin, "The reading of flat-print characters by the blind," Voprosy psikhologii, 1956, No. 5.
7. M.M. Germanov, "The transformation of typographic signs into signs accessible to the blind," Izvestiia Akademii Pedagogicheskikh Nauk RSFSR, 1957, Vol. 90.
8. M.A. Verbuk, "The reading for the blind of a typographic text by means of a conventional phonic signaling system," Izvestiia Akademii Pedagogicheskikh Nauk RSFSR, 1957, Vol. 90.

X

VISUAL PATTERN RECOGNITION: THE PROBLEMS AND PROMISE

by

Oliver G. Selfridge
Lincoln Laboratory
Massachusetts Institute of Technology

EDITOR'S NOTE:

This paper was read at the International Congress on Technology and Blindness, 1962, and will be reprinted in the Proceedings of that Congress.

Lincoln Laboratory is operated with support from the U.S. Army, Navy and Air Force.

I shall make remarks here of a fairly general nature. I think on the whole I feel very optimistic in the very long run of the abilities of our technology to aid the blind in pattern recognition; and, agreeing with Herr Kazmierczak, not very optimistic about the immediate prospects.

The astonishing uniqueness of man in general I think depends to an enormous extent on his perception and integration through his assorted senses of the world around him. I can see that it is the job of scientists, among others, to find out how they work and the job of technology to improve them prudently and appropriately. The power of our eyes, of course, is not in responding to light, but in seeing and recognizing patterns. The blind man does not necessarily need eyes alone; there is a horseshoe crab common on our East shore coasts called limulus, which has eyes which seem to work very well neurologically, except that nobody has ever been able to find out whether they influence his behavior at all. It is not mere photosensitivity, either; as we, this time of year, dutifully trudge to the beaches where we find horseshoe crabs, we realize anew that we are all covered with a spendidly photosensitive layer. The time constant is a little long for some purposes.

Nor is it sufficient to change the light signals, scanned in some way, merely to something else like sound. Eyes and ears have great powers, but they are very different in the ways they work, and in the kind of patterns they respond to. It is a chief thesis here that perhaps the people working on reading machines, myself included of course, have been insufficiently sensitive to the nature of the patterns which have to be detected and the nature of the patterns to which the other senses are most sensitive. What the blind need is a sensible level of decisions about the light patterns that the sighted see.

This is not the same as saying that they need merely photosensitivity. The decisions about the visual patterns ought to provide a balance of what is most useful and what is most feasible. Pattern recognition in general, of course, is not only concerned with visual patterns, but also with the abstractions we make from the data derived from all our senses. What matters to us in hearing speech is the patterns of the words rather than the individual sounds. In general we prefer to go higher rather than lower in levels of decisions when we can. Sometimes it is easy to specify an appropriate set of patterns which we are going to consider--a vocabulary, as it were, or an alphabet--or at least to narrow the choice. For reading machines, we may guess that we ought to present decisions about the letters or, more probably, about the words.

For other kinds of problems, as in navigation or guidance for the blind, there has been much too little exploration of the kinds of decisions about the environment which the blind man really needs, the kinds of patterns which he really should respond to. For that matter, we don't know what sighted people really respond to in looking at the environment. It clearly is not particular bits, that is, particular elements in particular places in his field of view. I shall come back to this later.

One of the things that makes recognition of braille very easy for a computer (and I suspect far from ideal for people) is that it is not a case of pattern recognition at all, insofar as I am using the term. There are just six bits, which correspond to 2^6, or 64 choices. Each bit is a very distinct bit (I am using "bit" in the technical sense, that is, a single binary choice). But the usual case of visual pattern recognition involves thousands or millions of bits. It is not just a case then of detection of a few fixed elements, but the recognition of complex variable patterns of thousands or millions of elements. In the patterns of many of them, some can be altered without changing the pattern, while to change one of the elements in a braille character is to change the character absolutely and unequivocably. It is only natural for us to be concerned chiefly with reading machines at the most direct and most obvious application of technology, this is certainly the one we have spent the most time discussing in these papers. For one thing, the context of a useful reading machine for the blind is one that cannot be considered well-specified yet, and is at least substantially more restricted than other more general kinds of visual aids.

I have said that the decisions ought to represent a balance of what is useful and what is feasible. Now, many things are not feasible at all today; feasibility does impart a limit. It would be pleasant and convenient could our reading machines read handwriting, for example, but they cannot and they won't be able to for some time. Even with print we have had all too little experience to say with assurance what is the most useful level of display of reading machines. It is possible (and by "possible" I mean without any great research and development program) to build today a machine that will read text in some given font of type and transform it into spoken words. That is, there is an absolute feasibility to do this, and I daresay that experimentally some part of this has already been done in fact, that some written text can be translated into spoken words albeit without any intonation or inflection. The machine will contain in its memory different recorded spoken sounds of a thousand or several thousand different words and would merely string them together and ship them out through a loudspeaker.

We don't know, of course, nor have we any idea in fact of how useful this would be. We can say some things about it. For one thing, the reading speed would be on the order of slowly spoken speech; I would suppose 120 to 150 words a minute. The words would not be strung together; however, I am convinced it would not be an impossible job for Haskins Laboratories, for example, to provide within a few years some kind of continuity of speech--to run a Vocoder, as it were, from the decisions about particular words that have been seen by the character reading machine.

I'm not necessarily advocating that approach, but it is the kind of thing we can do today at a level of absolute feasibility. It ought to be made very clear that this technique would involve a large digital computer. I think Herr Kazmierczak's estimates of cost are excessively low for this: $100,000 won't find much of a digital computer in this country--and I think you need a large one, and a lot of extra equipment too, to read at real-time speed. It would be of no use for a blind man who wanted to read the advertisements in a subway, or even to read a newspaper. It would require a fixed font; no digital computer is as yet very portable at all; and of course the kinds of type fonts and even the vocabulary, in advertisements as well as in the rest of the text, are not yet susceptible to pattern analysis. We know how, but we haven't in fact done so--and it is a long step, as I will say again and again, from knowing the general principles of approach to a problem like pattern recognition and knowing how to do it technologically.

There are two obvious questions that I can raise here: What can our technology do now or soon? and, What do we want it to do? We shall discuss them one at a time. There are several basic techniques in pattern recognition by machine. Again, I repeat, we are here concerned with the recognition of complex patterns of many elements rather than the detection of a few fixed elements; and of course I still use the general example of reading machines as a kind of local conceptual environment.

The most primitive technique I call "template matching." Here, the visual signals are converted wholesale into some string of bits, some string of choices, which as a whole are matched against stored replicas of the 26 letters. Herr Kazmierczak gave a summary of assorted ways of doing this; most of his techniques were essentially template matching. Sample letters have of course to be correctly positioned and oriented, and they have to be of the same type font, of the right size, and not too dark and not too light; and the background has to be more or less strictly controlled. It is easy to describe how to build a machine like this; building it well is another matter--but it is easy to describe how one should build it, and there may be many of you who are in fact associated with efforts of this kind. With typewritten material (that is, material written on a typewritter) there are in fact working systems available right now that use template matching. One can avoid some of the messier problems of positioning by clever scanning techniques. The IBM character reading machine now reads only numerals of the kind of font that they use in one of their printing machines (but I am told they will extend it to a full range alphanumeric characters). It uses a scanning technique in which it moves the image to be recognized through all or nearly all possible positions and waits for the best check. This is a perfectly sensible procedure. Very clearly, however, the kinds of extrapolation one can make from this technique are very limited. It does require the right font, it does require the right orientation, it does require the right size, it does require fairly careful control of noise. Unfortunately, handwritten or handprinted letters, spoken words, and even much printed text typically show very wide variations from any set of templates which can be prepared in advance.

We can do a little better by providing a metric to measure the degree of fit of the unknown image with every template and then pick the best fit. We can also supply transformations which normalize the unknown image, put it in the center of the field of view, and use some other kinds of judgments about the orientation which we have. These measures unfortunately do not, in practice, seem to rescue the situation. The greater the variability the less successful template matching becomes, and by our standards very little variability can reduce the performance of the system, as far as we have been able to find out, to unacceptable levels.

I have to conclude that for the general kinds of requirements as I see them, template matching in its pure form, modified by matching and normalization, is adequate only for printing and typewriting. I fear that an all-font print reader cannot be handled with template matching.

I have been told with some bitterness by store clerks and bank tellers that my signature is illegible--and so it is. But it is very easily recognized, none the less; even so it is never the same twice. Well, how is it "easily recognized"? (I can assure you it is easily recognized!) The answer is that it is recognized by having certain features or properties (one of which of course if illegibility--there are others). All of you who have legible signatures will not have your signature confused with mine by any bank teller. But there are many other kinds of properties too. These properties are typically not functions of any particular piece of the signature; the interesting properties are global properties, that is, functions of the signature as a whole. When Herr Kazmierczak spoke of the "particular parts of the image which have to be recognized," I envy him for being able to talk about this and to talk about the "particularly important parts of the character," because I think that many of the interesting and necessary features for recognition are those properties which cannot be specified or localized to a small part of the field of view, but are in fact functions of the whole field of view.

Characterizing shapes by their distinctive features or properties can ease the problem of variability. It is easy to specify features or properties which are invariant over a far wider range of letters than can be encountered by a like number of templates. What kind of features am I talking about here? There are many kinds of features. Connectivity is a global feature: is the letter singly connected or not? Does it contain a straight line segment? Is it wider at the top than at the bottom? and so on; these are all global features. There are some interesting features which are not global; a serif, for example, which turns out apparently to increase the legibility of a printed letter--that is not global. All too few of these features have been programmed or built into machines and we certainly do not have much operational experience with them.

We may also hope that a list of the properties of known samples can provide a basis for classifying unknown samples, and can even help us generate new features which will be even more useful. This property list--that is, describing the image by a set of properties--does not eliminate the problem of variability, but merely transfers it to another level. Yet, as far as we can tell, property or feature extraction is a step in the right direction and has proved to be much less fallible than a grand transformation which is intended to reduce all inputs to one of a finite sized set of templates. If the property list is appropriately designed the recognition does not necessarily lean strongly on any one feature, and may incorporate correlated or dependent properties for correcting errors in feature extraction. It will probably work well enough to be useful in situations where template matching is just completely inadequate. We have found, as I said, that we have discovered no easy way to build machines that use feature extraction; it seems to require a substantially greater complexity than template matching. But there are features and features. One kind of feature that I mentioned was the presence or absence of a serif, or worrying about connectivity. But there is another broad kind of feature.

Suppose our machine sees the word, T A _ _. Suppose the machine can also tell that the two blanks are both the same letter. That is clearly another kind of feature and a very useful one in this case, because it immediately restricts the possibilities from many scores of words to just one word, the word T A L L. This is a feature that interrelates the different parts of the word, and here it is a feature not of any single letter but a feature of the word. This general kind of feature I include in the term "the effect of context." Context in pattern recognition suggests the interrelation of decisions at different levels in the sense that the recognition of a letter is a different level of decision from the recognition of a word. Context in one form or another is an accompaniment of nearly all pattern recognition schemes if they are to be effective. Often this effect of context is implicit. Herr Kazmierczak mentioned that for human use it is not nearly so important to get every word right because we can rely upon the human to supply the effect of context and recognize the word rather than the individual letters. But to use context effectively will demand even more from the technology.

T A _ _, where the blanks represent the same letter, can be recognized only by a technique that has an acquaintanceship with a very large number of words of English. At a guess, Basic English (which is probably inadequate I would reckon) has a thousand words, each word containing on the order of 30 bits or so. It must also in the case I just spoke of be able to run rapidly through all of the four-letter words beginning with T, A. This kind of processing is not always a speedy one. If the words are stored alphabetically, running through all of the four-letter words beginning with T, A may be easy enough; but if we have _ _ L S, we then have to run through all the four-letter words that end in L S. This is much harder unless we happen to have a rhyming dictionary in the machine.

Let us suppose, then, that the demands for using context will be chiefly or easily met.

There are other kinds of problems of pattern recognition which I shan't go into in detail; but I can pose the questions of learning, that is, whether the machines themselves should take a major responsibility in learning or adapting to the exact nature of the patterns that they must recognize. There is no doubt of the power of this in general; after we have learned the habits of speech of a friend it is much easier to understand him over a noisy telephone. This learning can take several forms in the machine, even as it does with us. Not the least important of the forms of learning is the selection of suitable features for recognition or for incorporation into our pattern recognizers. All that I will say at this point is that many of us working in the field believe that the complex goals that we are aiming for will need the help of the machine for a large part of the learning job. We have had all too little experience in this.

When we try to get machines to illustrate their own abilities (and a large number of people are very concerned with the "glamour" of this), we tend to underestimate the truly amazing abilities people exhibit in recognizing patterns. Sometimes it is in merely carrying a particular technique to its extreme; more often it is in the combination of different kinds of techniques, different kinds of abilities, and integrating them together. I think this integration of many different techniques is probably the most impressive facility we have. In vision there are very many examples. We can recognize faces (by "recognize" I don't necessarily mean to recall the names; I find myself unable to do that most of the time), but we can recognize faces at a distance by clues that have not really been found. We do not really know anything about how we recognize a face, I'm afraid, in the sense of being able to build a machine to do the same thing. There is probably something to be learned from the cartoonists, who can capture (without verbalizing about it) the recognizable features of a face and present it to us. We don't know how they do it, and neither do they, but they do it. Whether this is something that we can find out how to build into machines or not, I don't know; we haven't looked into it in any case. The ability to recognize music on the slightest of cues, apparently, I think is absolutely incredible; half a second of hearing a Caruso record and you know that it is Caruso, even if you haven't heard a Caruso record for many years. It is very hard, looking at the waveform, to see what it is that you're recognizing, but I am sure that most of you have had this experience. A couple of bars of the Brahms Requiem, and you know that it is the Brahms Requiem; all of you have had many experiences of this type.

When we talk about pattern recognition we generally like to specify ahead of time, and we say, "Well, we ought to know the kind of vocabulary that we are recognizing." What is the "field of view," as it were; what are the choices? To me, the most amazing thing that people do is to recognize without any restriction of choices (that is, with the restriction of choices as broad as the whole of our experiences) and with very little difficulty that record of Caruso. To take another example: when I say, "The cow jumped..." all of you can finish the sentence. It is very hard to specify to a computer what kind of range of choices this represents without including all of the education of a person. Another example, at a higher grade level is, "How do I love thee?"--and you can all finish the phrase. I regard this as a very surprising kind of ability. The estimates of capacity of a computer which would be able to handle this task would not I think be merely in the thousands or hundreds of thousands of words.

Let me summarize now what our technology can do, having just presented some of the examples of what it can clearly not do, and what it shows no great promise of being able to do for quite some time. We can recognize patterns with machines if we can specify them well enough. Today, "well enough" means letters, but not faces; it means words, printed words, but not words in handwriting; it means printed letters, but not handwritten letters or script letters. We have only slight learning ability in our machines. In the learning process people are going to be an integral part of the learning process of the machines for quite some time to come. I say this very sadly, because a large part of my own effort is devoted to attempting to get the machines to do more of the learning. We can only do pattern recognition in fairly restricted and well-specified contexts. The effects of context in general are very ill-known. It is clear that they are important; the context of single words we can imagine building in, but we don't really know how to design or to optimize them. The advantages of course are clear; we can illustrate the advantages again and again in the ways people work, but we don't know how to apply these ways to machines as yet. We know that features are important; we can guess that features are crucial. But we don't know how to implement them cheaply or easily. We don't know what they ought to be.

A larger point, and one which I think concerns this audience even more, is that the contexts of use are not well known. They have, in fact, not been very well studied at all. Technology, as I see it, depends upon the orderly interaction of capabilities and experience. In the context of reading machines for the blind, most of the techniques and most of the capabilities have not been explored at all. We do not have an orderly feedback from operational experience. We depend upon experience to ask questions and to pose requirements on the technology. The technology has also been rather worse than unimaginative in responding to the requirements which have not been put in the form of requirements at all; it is not enough for technology to say, "We want to be able to read." The requirements have to be better specified than this. We must not demand that the blind be given guidance; that is not specifying. We are falling here into the same kind of difficulties that beset computer designers some years ago, upon the realization that computers could in principle do anything, but in principle the method has to be specified. To say that a machine can "think" is a kind of truism so long as we can in fact specify what "thinking" is in the right kind of terms.

One can make some further statements about the technology, too. The real kind of advances will come in making choices about technology, and I say that at present we have all too few genuine choices to make. When I say that we should have operational experience, I mean that the only value of operational experience to a technologist is in helping him make a sensible choice of courses of action. If not very many different courses of action can be posed the information he gets about this success will not be very great.

In conclusion, I think there are many layers of processing of visual signals to semantic content, and the reading device must present information at an appropriate level of pattern recognition. It is just not feasible to present information right now at the semantic level. We don't really know anything about the capabilities of people in accepting patterns at the different intermediate levels. We are beginning to find out a little bit about the effectiveness of spelled speech, but we don't really know about the ability of people, or their operational requirements, to handle these patterns at this level. We know the scientific principles of pattern recognition, and/or the generating principles. We have had almost no experience in putting them together in complex machines, and it is surely clear that in pattern recognition, the levels of decisions are going to be complex ones to be useful for guidance and navigation devices.

The demands must be set primarily from the abilities of the user to perform the integration that will be up to him, and we need not underestimate the kinds of integration that he can do. This information must be presented in terms appropriate to the particular nonvisual sense and appropriate to the as yet unexplored operational environment. We are not, it seems to me, very far along in knowing how to do this. Thus, while I am very optimistic about the long-range usefulness of technology, I am not very hopeful of substantial successes soon.

XI

IMPLICATIONS OF ALTERING THE DEFINITION OF BLINDNESS

by

Irvin P. Schloss
Legislative Analyst
American Foundation for the Blind

EDITOR'S NOTE:

> Mr. Schloss was requested to prepare this article on implications of altering the definition of blindness with special reference to research, legislation, fund-raising and services, etc. The article in this way may be considered an introduction to the following articles on various aspects of definition of blindness.

"More people are blinded by definition than by any other cause," wrote Lloyd H. Greenwood in 1949 in a column called "Shots in the Dark," which appeared in the BVA Bulletin, the publication of the Blinded Veterans Association.

This trenchant observation by an individual who had been totally blinded just five years before it was made serves admirably to focus attention on a major anomaly of work for the blind--the definition of blindness generally used by public and voluntary agencies as the criterion of eligibility for special benefits and services.

As a patient in army hospitals, Greenwood lived with, trained with, and observed at close range other World War II eye casualties. Among them were totally blind individuals like himself; those who could tell visually whether the light in a room was on or off; those who could make good use of some residual sight to see where they were walking but could not use it to read; those who could read a word or two at a time with strong lenses but could not read for more than a few minutes at a time; those who could read newspapers but who could not see too far ahead of them; and others who had virtually perfect sight limited to a severely restricted visual field. In other words, his fellow-patients were individuals with many different kinds and degrees of visual impairment resulting from injuries to the eyes, the optic nerves, or the brain, or resulting from infections or other diseases. Only some of his fellow-patients were what he and they had always thought of as being blind.

Late in 1945, Greenwood became the first Executive Director of the newly organized Blinded Veterans Association; and through extensive reading, conferences with leaders in work for the blind, and personal observation of various types of programs and activities for blind people, he discovered that nearly all of the men with whom he had been hospitalized were considered and called "blind" by national and local, public and voluntary agencies which administered benefits or operated service programs for blind people. Even though many of the people eligible for service had varying degrees of useful sight, and even though many of them performed as sighted persons in various aspects of daily living, they were all, nevertheless, classified as "blind."

The determining factor was whether their distance vision measurement or visual field came within the measurements for these two factors specified in the so-called legal definition of blindness; viz., central visual acuity of 20/200 or less in the better eye with correcting lenses, or contraction of the visual field to 20 degrees or less if central visual acuity is greater than 20/200. This definition of blindness has become a rigid criterion of eligibility for benefits and services, even though the two vision measurement factors it utilizes makes some people who do not need certain specific services eligible for them and excludes others who would clearly benefit from these same services.

Before I discuss the shortcomings of the present definition of blindness and the implications of altering it, it would be useful to recount some of its history and background. At the request of the Department of Public Welfare of the State of Illinois, a committee of the Section on Ophthalmology of the American Medical Association was appointed to develop "...a definition of blindness in scientific terms, that might be made statutory..." The result was several definitions of blindness which were incorporated in a resolution of the Section on Ophthalmology adopted by the House of Delegates at the 85th Convention of the AMA, held in Cleveland in June 1934.

The definitions of blindness in the AMA resolution are as follows:

> "Total blindness is inability to perceive light; lack of light perception. The person who is totally blind cannot tell whether strong light falls on his eyes or whether they are in total darkness. Light perception is vision such as one has when the eyelids are closed.
>
> "Economic blindness is absence of ability to do any kind of work, industrial or otherwise, for which sight is essential. In general, visual acuity of less than one tenth has been classed as economic blindness, meaning that objects can be recognized only when brought within one tenth of the distance at which they can be recognized with standard vision. Such vision in the better eye when corrected with the best possible glass would be recorded as less than 0.1 or 6/60 or 20/200, or as an equally disabling loss of the visual field.
>
> "Vocational blindness is impairment of the vision that makes it impossible for a person to do work at which he had previously earned a living. He may still have vision enough to do some other kind of work that may yield him an adequate support. Such vision in the better eye with the best possible correcting glass may vary from one tenth to one third; that is, from 0.1 or 6/60 or 20/200 to 0.3 or 6/18 or 20/60, depending on the vision required for the occupation previously followed.
>
> "Educational blindness is such loss of sight as makes it difficult, dangerous or impossible to learn by the methods that are commonly used in schools. This necessitates two types of schooling for such individuals; namely, sight saving classes and schools for the blind. The requirement for admission to sight saving classes is vision in the better eye with the best possible correcting glass of less than 20/70 and more than 20/200.
>
> "The requirement for admission to the school for the blind is vision in the better eye with the best possible correcting glass of 0.1 or 6/60 or 20/200 or less."

Following the enactment of the Social Security Act in 1935, the Social Security Board modified the AMA definition of economic blindness to include visual acuity of 20/200 and spelled out the visual field defect of 20 degrees or less. On September 15, 1936, the Board recommended this modified definition of economic blindness to the states for their use in administering the aid to the blind program under Title X of the Social Security Act.

Over the years, this same modified definition of economic blindness came to be used as an administrative criterion of eligibility for most services and benefits for blind persons, including those provided by Federal statutes enacted before and after enactment of the Social Security Act. However, it is worth noting that this definition actually appears in only two statutes--the law granting an additional income tax exemption for blindness and the law providing automobiles for amputee and blinded veterans, with the definition called impairment of vision rather than blindness in the latter.

One other Federal law, Section 216 of the Social Security Act, which provides for "freezing" wage credits for disability insurance purposes, defines blindness as 5/200 or less in the better eye with correcting lenses, or contraction of the visual field to five degrees or less. Also, the Veterans Administration statute on disability compensation lists visual acuity of 5/200 or less in the better eye with correction, blindness of both eyes having only light perception, and anatomical loss of both eyes as criteria for progressively higher compensation awards. In all other Federal laws and in parts of those mentioned above, blindness is defined in administrative regulations--not in the laws themselves.

Undoubtedly, the non-medical concepts incorporated in the 1934 AMA resolution to describe economic, vocational, and educational blindness had a considerable influence in minimizing the ability of people with the degrees of visual impairment listed and contributed to the acceptance of the 20/200 definition of blindness, with the qualifying adjective "economic" omitted. The resolution emphasized the individual's disability and minimized his visual and general ability, despite the fact that many individuals with the varying degrees of residual vision encompassed by these definitions can and do make excellent use of their sight in their jobs and other activities.

It is probable that two factors, one of them completely unrelated to visual performance ability, had a significant influence on the AMA committee. First, the definition was proposed and adopted at a time when the country was at the height of the depression of the '30s, when millions of unimpaired persons were unemployed. Second, ophthalmologists still considered it harmful for an individual to use his residual vision for fear of losing it altogether. Thus, program administrators and workers for the blind understandably accepted these individuals as eligible for services and benefits because, according to the experts, they were blind for all practical purposes.

Needless to say, the implications of so broad a definition of blindness encompassing so many widely differing degrees of visual impairment have been considerable.

The rigid commonly used definition of blindness has been detrimental to the best interests of the totally blind, the partially seeing, the agencies which serve them, and the public which supports all programs through taxes or philanthropy. The following are among the factors which should be considered:

1. The definition presently excludes people who need some services. For example, the Books for the Blind program of the Library of Congress excludes people who have better than 20/200 visual acuity but who nevertheless cannot read print. (The definition does not take into account near vision, which is a better criterion of reading ability than the distance vision measurement it uses.) Large type books produced with Federal funds through the program of the American Printing House for the Blind are available to children within the definition who can read print but not to children with slightly better visual acuity who still need large type books.

2. The definition dilutes the effectiveness of certain programs. For example, the Federally-financed part of the program of the American Printing House for the Blind, initiated in 1879 by the Congress of the United States as "an Act to promote the education of the blind," has included the large type inkprint books mentioned above in recent years, thus reducing the amount of braille material, tactual educational aids, and tangible apparatus available for blind children who cannot use their sight in their education. Yet the needs of totally blind children for books and special educational aids are not being adequately met.

Although a valid case can certainly be made for Federal assistance in the production and distribution of large type books and other special visual aids for all children with a serious visual impairment, whether or not they meet the criteria of the definition of blindness, the validity of including such a program within the scope of one designed for the blind may be subject to question.

3. The definition of blindness excludes many people who come within its criteria from valuable services and benefits because they do not consider themselves blind or do not wish to be considered blind.

4. The definition tends to retard the development of adequate services for both the totally blind and the partially seeing in programs where they are considered together without regard to the special problems and specialized needs of the several different groups they include.

5. The definition complicates research in all aspects of work for the blind, since the label "blind" is applied to a group with so many diverse visual performance characteristics which could significantly influence other types of performance. Unless the subject group in a research project involving the "blind" is clearly and specifically defined, I find it necessary to question the results and conclusions insofar as visual characteristics and performance may be factors influencing them.

6. The definition further complicates an already complex problem of public misunderstanding and misconceptions about blind and visually impaired persons and is detrimental to the best interests of both the totally blind and the partially seeing. Organized public education activities which describe the accomplishments of "blind" people when the currently accepted definition is used adds to the confusion of the public.

An individual not actively engaged in work for the blind generally uses the term "blind" for persons who are totally blind and applies terms like "almost blind," "nearly blind," "virtually blind," "partially blind," "partially sighted," "partially seeing," "extremely near sighted," "near sighted," or no label at all to persons they observe to have a greater or lesser degree of visual impairment.

Even professional workers have difficulty at times when it comes to the use of the term "blind" for people within the current definition of blindness who still have considerable useful vision and the term "partially seeing" for people with visual acuity between 20/70 and 20/200.

7. The current definition provides useable limits for statistical purposes, but the question of what the statistics truly show inevitably must arise.

In recent years, increasing attention has been given to the question of the adequacy of the current definition of blindness; and two groups financed by agencies of the Federal Government have been examining it. The group whose activity is most pertinent to the present discussion is the Workshop on the Definition of Blindness, which is being conducted under the auspices of the National Institute of Neurological Diseases and Blindness.

The Workshop is under the chairmanship of Dr. A.E. Braley, Professor and Head of the Department of Ophthalmology at the State University of Iowa, and consists of representatives of national public and voluntary agencies, as well as several ophthalmologists. At its meeting on October 12, 1962, the Workship unanimously adopted the following:

"I move this committee go on record as recognizing two major types of visual disability:

"(1) Blindness includes individuals with no light perception and those with no light projection;

"(2) Visual impairment of an advanced degree.

"Visual impairments may be influenced by a variety of motor, sensory, and psychologic factors which govern the performance of visual tasks and consequently may lead to visual disability.

"Visual impairments arise from interference with one or more of the visual functions."

Although this initial statement will undoubtedly be refined and amplified as a result of further action by the Workshop and specific studies recommended by it, it represents a major first step of great significance. The terminology it recommends would restrict the application of the terms "blindness" and "blind" to individuals who are in fact totally blind or who have light perception without light projection. The term "visual impairment of an advanced degree" would be used to apply to individuals with vision problems who still have varying degrees of useful vision.

It is obvious that this second category of people--by far the larger group--will need to have the nature and extent of their vision problems specifically delineated. Using the present definition of blindness as the criterion of eligibility for needed services and benefits for the "visually impaired" would prove to be just as inadequate and misleading as it has been as a way of delimiting those individuals in our society who are "blind." For the distance vision measurement or the visual field measurement are only two of many factors which, when taken together, provide a much more adequate indication of what an individual sees.

Without doubt, a scale or index of visual efficiency will ultimately be evolved as a more accurate and adequate indicator of services an individual may require. In another article in this publication, Dr. Richard E. Hoover described the many visual performance characteristics which combine to indicate an individual's visual efficiency.

What are the implications of the Workshop statement and the further development of visual efficiency as the criterion for services? Without question, the results of general acceptance of these concepts will be beneficial and positive, focusing truly specialized services according to the needs of the truly blind and the different groups who have visual impairment of an advanced degree.

More visually impaired individuals with conditions which can be helped by visual aids will certainly come forward for this service without the psychological barrier of being called "blind." Ideally, vocational rehabilitation specialists for the blind would be individuals trained and experienced in working with the truly blind, while other specialists would be assigned to the visually impaired. The Books for the Blind program would serve everyone with a visual impairment severe enough to prevent him from reading inkprint comfortably over a period of time.

From the standpoint of research, there would no longer be any question about the nature of the visual characteristics of the subjects in a study involving the blind. Research studies of the visually impaired would logically be expected to include an accurate description of the visual characteristics of the subjects if these were factors which could influence the results.

For the first time, statistics on the blind could be compiled with accuracy; and assuming the development of useable visual efficiency criteria, accurate statistics on the different groups with visual impairments of an advanced degree could also be compiled.

Altering the definition of blindness as indicated above would simplify present problems of public understanding, since separation of the truly blind from the visually impaired conforms to existing public conceptions. Public education programs which presently call both groups "blind," have served to confuse rather than promote better understanding. The task of public education would be simplified.

Agency fears about fund-raising ability with the altered definition are basically groundless. The problems of people with visual impairments of an advanced degree are as genuine as the problems of blind people, even though they may differ. Public appeals for funds to assist the visually impaired to solve their problems would be as effective as any appeal on behalf of the blind if a straightforward, honest approach were used. Appeals to foundations or government agencies for grants to specific projects would not be affected by the change.

One of the concerns about altering the present definition of blindness is the effect this action might have on the numerous special benefits provided for the blind by Federal law. As I indicated earlier in this article, most of the Federal laws do not define blindness, leaving the criteria of eligibility for the benefits to administrative regulations. Therefore, it would be desirable to alter the enabling legislation in situations where visually impaired persons should also be entitled to specific benefits. For example, in Titles X and XVI of the Social Security Act, which provide public assistance payments as well as social and rehabilitative services under the heading "aid to the blind," it would be necessary to amend the law to read "aid to the blind and visually impaired," still leaving to administrative regulations the determination of the degree of visual impairment required for eligibility.

I believe that this kind of amendment to existing laws would be easy to realize and would not create confusion, as some people fear. In my experience, congressmen, senators, and Congressional committee staffs are intelligent people who can be expected to understand the significance of and need for such changes as long as the people requiring the services and benefits provided by law are adequately served.

From every standpoint, altering the present definition of blindness to more accurate terminology utilizing visual efficiency as the principal criterion for service needs will serve to sharpen and improve services to the truly blind and the visually impaired.

VISUAL EFFICIENCY AS A CRITERION OF SERVICE NEEDS

by

Richard E. Hoover, M.D.

EDITOR'S NOTE:

This article is from the PROCEEDINGS of the Thirty-sixth Convention of the American Association of Workers for the Blind, Inc., 1962. Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

"Psychologists are agreed that each person possesses the same human characteristics. They are also agreed that differences found between individuals are not due to one possessing one set of traits and another a different set. The differences found are due to these various individuals having unequal amounts of these traits, which produce assorted patterns of performance."[1]

---

[1] Kuhn, H., Stump, N.F., Tolman, C.P. and Kutscher, C.F., "Industrial Ophthalmology," Reprint, American Academy of Ophthalmology and Otolaryngology, July-August 1946.

It is the adequate classification of visual efficiency which particularly interests us here.

Let me begin with my definition of visual efficiency. Visual efficiency is a complex of measurable visual characteristics which, when combined with other sensory and physical characteristics, provide an opportunity to utilize sight--opportunity implies motivation or incentive.

Sensory and physical characteristics are meant to include the psychological, intellectual and all other sensory modalities in addition to sight, as well as the motor skills and anatomical variations.

Today, I shall discuss the importance of visual efficiency and try to show you how visual acuity, especially for distance, plays only a part in the determination of visual efficiency. I shall also discuss the other visual, sensory and physical characteristics involved in visual efficiency and how these should be measured when possible. Finally I shall try to impress you with the need to measure, predict, preserve, restore and improve visual efficiency when at all possible.

The universe is bathed with light and sight, and as long as this is so, while perhaps not absolutely essential, visual efficiency will always remain important.

The most obvious examples of demands for good visual efficiency are in requirements for pilots, astronauts, crane operators, game hunters, proofreaders, accountants, etc. One of these requirements is usually good visual acuity for distance, but it is not the only one, nor is it always the most important. Sometimes, even though visual acuity may diminish, visual efficiency can be preserved at its previous level. Our everyday environment is geared to certain visual efficiency levels so that at some point of diminished visual acuity other visual, sensory and physical characteristics must compensate if we are to meet the necessary visual efficiency requirements.

This complex of visual characteristics will be discussed under three main headings:

(1) Visual Acuity
(2) Visual Versatility
(3) Visual Capacity

Visual acuity is the one characteristic most often talked about, most often and most easily measured. It is also quite unfortunately and quite erroneously often confused with visual efficiency.

Visual acuity is the measurement of the resolving power of the retina in angular terms of minutes. The common expression 20/20 represents the ability of the retina to resolve a visual angle of one minute of arc; 20/200 represents the ability of the retina to resolve a visual angle of 10 minutes of arc. It is fortunate that we have this very logical and precise way of measuring retinal function, for this makes it possible to measure visual acuity at any distance from infinity to the anterior surface of the eyeball. It is essential that it be measured at certain standard distances, usually at least two--sometimes more, if it is to represent its constant and effective power in any visual efficiency equation.

Because it is not always possible to project an optically distinct image of the same angular size of the retina for both distance and near, there will often be paradoxes between the two. Distant vision can be excellent and near vision poor, or near vision excellent, and distant vision poor. This will depend upon optical, anatomical or pathological conditions of the eye. The point to emphasize again is our ability to measure it at any distance with extreme and consistent accuracy under any given set of standard conditions. This is the visual measurement to which you are most often exposed.

Let us leave visual acuity at this point and discuss the measurement of the characteristics I have placed under the heading of "visual versatility."

Optical power--the emmetrope has more efficiency for both distance and near than does either the astigmat, the hyperope or the myope, but with our retinoscope we can determine the refractive state with extreme accuracy in most instances.

Accommodation--this can be measured very accurately with conveniently common methods for any distance within infinity. In the normal eye it can even be quite accurately predicted at any given age.

Convergence and divergence ability--the ability of the two eyes to turn toward and away from each other. We have methods and instruments to accurately measure these important ocular abilities. The same is true for the following functions:

Ductions and conjugate movement ability
Light and dark adaptation
Color perception
Field of vision--(size, form and color)
Aligning ability
Binocularity

All of the above can be quite accurately measured in either the normal state or pathological state, and they are the characteristics in the normal intact eyes which give us visual versatility.

Now, let us examine the characteristics I have grouped under the heading of "visual capacity."

Capacity infers load and duration under certain standard or other conditions. You have heard that it is possible to accurately measure all the characteristics listed under visual versatility. Now, let us ask if we can measure the length of time, amplitude and under what conditions we might maintain our present refractive error, our accommodation, our convergence, divergence, conjugate gaze, light sensitivity, light and dark adaptive power, color perception, field, aligning ability or binocularity. We can measure all of these and we can either predict or measure our ability to maintain these functions under different conditions of health, fatigue, stress or isolation and media.

Visual efficiency can be influenced and altered by the other sensory and physical characteristics I mention in the definition. Let us examine the possibility of measuring some of these.

We certainly can measure height and weight. We can also measure muscular power and endurance. We can also measure most motor skills. We can measure intelligence. We can measure certain aptitudes. We can measure hearing, touch, taste and smell.

Now, since the importance of visual efficiency is so apparent, would it not be advantageous for us to measure it, if we can? I have suggested how it is possible to measure the individual ingredients which make up visual efficiency, so there is no logical reason why we cannot measure visual efficiency to an accuracy never before tried--especially among those who have more than the usual degree of visual impairment.

We could, in certain instances, learn to partially predict it from diagnostic pathology alone, e.g., albinism, retinitis pigmentosa, macular degeneration, and so forth. All have rather constant visual characteristics and vary mostly in the sensory and physical characteristics of their possessor.

If individuals with visual impairments had all of these characteristics measured and recorded we would then begin a foundation of useful knowledge which would help us to determine which individual with which amounts of these characteristics could, under certain conditions, consistently perform so many of the common tasks which require some degree of sight, e.g.: What is the pattern of characteristics which allows one to recognize people at 10 feet, 5 feet, etc.? What is the pattern for those who can successfully operate bicycles, wheelbarrows, lawnmowers, motorcycles, tractors, trucks, automobiles, etc.? What is the pattern for those who can detect steps up or down at a fixed distance which are necessary to level an elevator? What is the pattern for those who can distinguish between a teaspoon and a tablespoon, a fork and a knife, a salt and pepper shaker, between a celery stalk and an orchid? If we would also analyze the visual requirements of these tasks, soon we could adapt visual efficiency patterns for certain visual tasks requiring these patterns with a greater degree of accuracy. Then, the mystery of the individual with a recorded visual acuity (the only characteristics recorded) of 5/200 doing some apparently miraculous visual feats would be solved.

Now, how can we preserve or restore visual efficiency? Certainly the contributions of medicine, surgery, genetics, the social sciences and the physical sciences all play their part. Sometimes these contributions would be more frequent and fruitful if those most interested would work together in seeking these contributions. It can be done with attention, not to one, but to all the important characteristics.

I consider myself a special worker for the blind, and so do most ophthalmologists. However, most of our interests are directed to the prevention of loss of visual acuity and the restoration of any loss through medicine, surgery, training and optics. I think I can speak for the profession and say we would in general lend our support and talents to a program of measuring visual and other characteristics on a more consistent, comprehensive and accurate basis if such data were to be used in the same accurate and constructive manner. We would certainly continue our interest and support in the improvement of visual efficiency. This we would do with continued effort in the clinic and the laboratory, as well as in our search for better optical devices, more knowledge in the use of color, etc. We shall also continue our support to education and training programs in the use of special methods, instruments and prosthetics. This is an area capable of rapid and productive expansion, e.g., in the training of the use of certain optical aids.

What I have said infers that visual efficiency is a complex of measurable characteristics, one of which is visual acuity, and that visual efficiency is extremely important and a far better guide to performance than visual acuity. I have also tried to impress you that these characteristics can be measured and how visual efficiency might become a practical guide to service and performance.

THE PROBLEM OF DEFINITION OF BLINDNESS

by

A.E. Braley, M.D.

EDITOR'S NOTE:

This article is from the PROCEEDINGS of the Thirty-sixth Convention of the American Association of Workers for the Blind, Inc., 1962. Gracious permission is given the American Foundation for the Blind to publish this paper in this issue of the RESEARCH BULLETIN.

There are numerous problems regarding the visually handicapped that require study. In order to be as helpful as possible, the National Institute of Neurological Diseases nd Blindness Council saw fit to give a small grant for a workshop on the "Definition of lindness." The first meeting was held on January 28, 1961, in Washington, D.C. An ffort was made to bring together people from several Federal agencies, from private gencies, and ophthalmologists, to study the problems. Each of the people represented pecial interests in the field of visually handicapped persons.

Each of the states has definitions for blindness which are based primarily on ehabilitation and welfare services. Nearly all the states use acuity of 20/200 or less n the better eye as a requirement for rehabilitation. Very few states define the visual field. I would like to quote a few examples of the state requirements.

Colorado: "The criteria of visual disability established to delineate the responsibility of this Agency: Central visual acuity not exceeding 20/200 in the better eye with corrections; or, visual field defect in which the peripheral field is contracted to such an angle of no greater than 20 degrees.

"Persons whose vision is greater than defined above will be referred to the General Rehabilitation Division, except where the prognosis indicates that the individual's loss of vision will eventually place him within the definition of blindness stated above."

Here the field of vision is included as a requirement and also the prognosis of the future vision. The ophthalmologist must report to the General Rehabilitation Division.

Connecticut and Delaware are similar to Colorado. In Connecticut the State Board of Vocational Education cooperates with the blind agency to serve the clients.

Hawaii is so interesting I think it would also be interesting to quote: "Visual handicapped, defined. Any person who has a visual defect which for him, in reference to his native abilities, training and education, constitutes an employment or work handicap shall be deemed visually handicapped within the meaning of this part. Blind, defined. The word blind as used in sections 109-6 to 109-12, whether so used as adjective or as noun, means blind or visually handicapped."

Massachusetts says, "Central visual acuity not exceeding 20/200 in the better eye after correction or the peripheral field of his vision to be contracted to the 10 degrees radius or less as measured with a six mm (6) white test object regardless of visual acuity." This is the best definition of the size of the field and the test object.

Minnesota, on the other hand, has none. The service for the blind is based on the following definition. "Persons having a visual acuity of 20/60 or less in the better eye, or having a corresponding defect in the visual field are considered blind under the Minnesota law. If the diagnosis of the eye condition shows a progressive disease which may lead to blindness, such as glaucoma, retinitis pigmentosa, etc., such cases must be referred for rehabilitation services to the service for the blind of the department of Public Welfare."

Pennsylvania is different from most, in that visual loss is based on percentage of visual function. "...., is defined by State statute as constituting a thirty percent (30) or greater loss of visual functioning. Cases not involving 30 percent or greater loss of visual functioning may be eligible for vocational rehabilitation services from the State Board of Vocational Education through its Bureau of Rehabilitation."

I was unable to find the formula they used to arrive at the percent of visual loss, but I assume it is based on the AMA committee report of 1934.

Fonda, in The New Outlook for May 1961, suggests that "...blindness may be defined as follows:

"1) Vision of 20/200 or less in the better eye, or in both eyes with best corrective glasses.

2) Vision better than 20/200 in the better eye with best corrective glasses and with a visual field constricted to 20 degrees or less in the widest diameter, using a 3 mm white test object at 330 mm or an equivalent isopter."

He further believes that for rehabilitation purposes the person must be classified as follows:

"Group I --Light perception to 1/200.
Group II --2/200 to 4/200.
Group III --5/200 to 20/300.
Group IV --20/250 to 20/70."

"The purpose of this classification is to establish an arbitrary standard for the greatest use of residual vision."

He further proposes "that individuals in Group I should be taught braille, whenever possible; Group II cases should be encouraged to read with aids"; but, he says "often (he has) difficulty in deciding what to advise for specific individuals in this group." "Groups III and IV should be taught to use their eyes."

These definitions are primarily intended for rehabilitation and public welfare. The importance of education of partially seeing cannot be under emphasized.

Jones of the Office of Education of the Department of Health, Education and Welfare says: "Education of visually handicapped children entered a new era when it was recognized that use of vision seldom if ever results in damage even by children with serious impairments." This is based on statements made by many well-known ophthalmologists. He further states that "the realization began to grow that some children with limited vision not only could be, but should be, put back into regular classrooms for all or part of their education." This is certainly true of the children, but how about the greater number of people who become handicapped after the age of 40? According to the "Census of the Blind in New York State, December 31, 1959," published by the Commission for the Blind of the New York State Department of Social Welfare, 76 percent of New York State's blind population were over 40 years of age and 47 percent were over 65 years of age. The statistical department of the National Society for the Prevention of Blindness has estimated on a national basis that 80.4 percent of the blind population of the United States is over 40 years of age and 51.8 percent is 65 years of age or over. There is no doubt that many of these people have cataracts, but many have hereditary defects. Fonda stated that, in 449 consecutive subnormal vision cases, hereditary defects were the largest single cause of subnormal vision.

Many of these people with 20/200 or less find it almost impossible to read even with reading aids. They should be tried, however. This group of older people represent a portion of the visually handicapped that are poorly handled by our national rehabilitation commissions.

After considerable discussion, Dr. Masland summarized that he felt "five different definitions could be given:

1) definition of blindness for the reading public
2) as it relates to need for prosthesis
3) relates to public assistance, social security, income tax exemption

4) needs for, and specific kinds of social rehabilitation
5) statistical projection of incidence of blindness in the country and the needs of these various services
6) workman's compensation payments."

Several avenues of approach to a definition of blindness then were apparent. Our Workshop could dogmatically write a definition that might be acceptable to all the states and services. The Workshop, however, felt that a more sensible approach would be to gather as much data from the field as possible. There was not thought indicated or implied that we were investigating the various agencies. We wanted to find from each agency what they did and what their rules were. A comprehensive questionnaire was developed by Dr. Graham and Miss Hatfield and the form was pretested. In the pretest, it was discovered that many problems were brought out by the form itself and many agencies could not answer the questions without explaining the answer. Since then Dr. Goldstein has revised the form, and another pretest is being undertaken. Many of you have received letters from me asking your cooperation in this pretest.

Since many of the definitions are based on visual acuity and visual field, another subcommittee of the Workshop was named to carry out another survey among the ophthalmologists. Dr. Leinfelder, Dr. Hoover, Mr. Bledsoe and Dr. Goldstein were on this committee. The letter was sent to a selected group of ophthalmologists drawn at random by Dr. Goldstein so that a large sample of practicing ophthalmologists would be represented. The response to say the least was very poor: 291 forms were sent out, 33 returned and only 4 of these were complete. The form is now being pretested in low vision clinics.

A definition of blindness is complex and requires multiple subdivision. The definition of Hawaii is good but so complex that it would be most difficult for an agency to administer.

While our Workship will continue to gather data, perhaps we could make some constructive statements.

1) Visual deficiencies from any cause should be made "a compulsory reportable disorder." The border line should be all cases that are based on driver's licensure cut-off point.

2) Ophthalmology societies should appoint a committee of all interested people to review the present definitions in light of present knowledge.

3) Educators should begin a longitudinal study of the children in schools for the visually handicapped.

4) All rehabilitation agencies for the blind should name a central group to work with the Department of Health, Education and Welfare and National Institutes of Health to gather data and settle misunderstandings. This could be a reactivation of the Committee on Central Statistics of the Blind.

5) Education of the practicing ophthalmologists by state agencies and national groups to give the best service for their patients.

PROBLEMS IN DEFINING AND CLASSIFYING BLINDNESS

by

John Walker Jones

EDITOR'S NOTE:

This article was originally published in THE NEW OUTLOOK FOR THE BLIND, April 1962. Gracious permission is given the American Foundation for the Blind to publish this article in this issue of the RESEARCH BULLETIN.

Mr. Jones is a specialist in the education of the visually handicapped in the Office of Education, Department of Health, Education and Welfare, Washington, D.C.

Much confusion stems from terminology presently used to describe visually handicapped children. This confusion tends to make it difficult for teachers and administrators to plan, evaluate and justify special programs. It also complicates the collection of basic statistics and estimations of incidence and prevalence in this area of special education. The growing concern of educators about problems related to defining and classifying blind and partially seeing children is summarized in this article. A brief review also is made of some program adjustments and of attempts by educators to refine the process of pupil selection and dismissal.

Little more than a decade ago, it was commonly believed that children with limited vision would damage their eyes if they used them to full extent for school work. Special educators encountered relatively minor problems in selecting pupils believed to be in need of placement in special programs. These educators found that their practices tended to support the application to school programs of the accepted definition of 20/200.* Many applied this definition to education even though it had been developed primarily for use with adults in determining their eligibility for public assistance or for vocational rehabilitation. Similar experience was found with the visual acuity of 20/70 to 20/200 for children placed in special education programs for the partially seeing. As long as use of residual vision was believed to be associated with ocular damage, few educators or parents were concerned about the fact that many children selected primarily on the basis of their visual acuity and taught to read by means of braille, had enough vision to read print. Very few were concerned that many children placed in special programs for partially seeing students demonstrated the ability to read ordinary print with reasonable efficiency and appeared able to progress well in regular school programs.

Seeking New Guidelines

Education of visually impaired children entered a new era when it was recognized that use of vision seldom if ever results in damage, even where serious impairments are present. With this new era came a renewed interest in exact refractions and in the use of low vision optical aids. With this new era also came a questioning of educational practices by educators, eye specialists, and parents of children with visual limitations. Empirical evidence began to indicate that under proper conditions many of these children learn to make good use of even slight amounts of residual vision. The realization began to grow that some children with limited vision not only could be, but should be, put back into regular classrooms for all or part of their education. New teaching techniques and types of special education programs began to evolve. Educators became dissatisfied with the visual acuity cut-off points on which many had relied so extensively in the past. They began to seek new criteria for defining, classifying and placing children.

---

*Most state and federal laws pertaining to blind persons define blindness for various official purposes as a visual acuity in the better eye with best correction which does not exceed 20/200 or a defect in the visual field so that the widest diameter of vision subtends an angle no greater than twenty degrees. The person with 20/200 visual acuity is able to recognize from a distance of twenty feet objects which those with average vision see at a distance of 200 feet.

The search for new guidelines to aid in classifying and defining visually handicapped children has gathered momentum in recent years. This is reflected in the following excerpts taken from the literature. Participants in a national conference on the education of blind persons in 1953 stated:

> The generally accepted definition of blindness places 20/200 as the dividing line between individuals considered legally blind and individuals considered sighted. However, this arbitrary definition does not seem realistic as applied to the educational needs of all children whose visual acuity falls below 20/200. Some...below this dividing line have unusual visual efficiency and, on the basis of recommendations of their ophthalmologists and the observations of their teachers, may be better off--physically, psychologically, and socially--through using their vision in their education.[7]

Educators of partially seeing children reinforced this statement in one of their publications in 1959 as follows:

> Experience has shown that many children with visual acuity of less than 20/200 can see well enough to make use of the equipment and special education media provided for the partially seeing and should, therefore, be identified as partially seeing rather than blind.[5]

The overlap between the definitions of blind and partially seeing children has had many ramifications. Participants in a conference on teacher preparation programs suggested:

> The large number of children who seem to fall within both categories can be separated and constructively served only if we are able to view these children according to a functional definition which describes the child, with all of his potentialities and needs after medical, psychological, and sociological information has been considered in terms of the best possible educational placement. This makes it necessary and very important for teachers of blind children to have the related knowledge concerning the education of children with varying degrees of visual problems.[8]

An eminent ophthalmologist stated recently:

> Classification of blindness is necessary because definition of blindness includes vision ranging from no light perception to 20/120. Only the totally blind need no definition. For all practical purposes, therefore, classification of residual vision is necessary to aid in the placement of partially seeing persons.[4]

He recommends that persons with vision of 1/200 or less be taught to read by means of braille but that those whose residual vision exceeds 2/200 be encouraged to the highest degree possible to read by means of print.

A small study of conference specialists in the education of visually handicapped children was called by the Section on Exceptional Children and Youth of the U.S. Office of Education during the summer of 1960 to study the definition and placement of these children.[1] Several tentative recommendations were made including:

A) Educators should seek to develop functional educational definitions of blind and partially seeing children rather than rely on definitions used by medicine, rehabilitation, and welfare.*

B) The current definition of legal blindness is of little use to educators either as a definition or as a criterion for placement. Immediate proposals to change existing state and federal laws, however, probably would be premature until further study has been given this important problem.

The following were among suggestions submitted by this group for further study and research exploration:

1) The educational classification of blindness should be reserved for children who have no measurable vision or vision which is so limited as to be of little if any practical use as a channel of learning. Such children use braille as their primary mode of reading and as an important source of learning.

2) Partially seeing children would be those whose visual limitation interferes with their learning efficiency to such an extent that they require special teaching services and aids if they are to attain performance standards appropriate for normally sighted students of comparable ability but who rely on vision as a chief channel of learning and use of print as the primary mode of reading.

3) Recognizing that some children with limited vision cannot be classified readily as either blind or partially seeing, a third or borderline group was suggested to include those partially seeing children able to use vision as an important channel of learning, some of whom may read by means of both print and braille.

Further evidence of need to resolve some of the issues pertaining to defining and classifying blind and partially seeing children and of the possible magnitude of the problem were revealed by a study conducted in the Office of Education. This study was based on information provided with the registration of children with the American Printing House for the Blind in January of 1960. Analysis and comparison of data on more than 14,000 "legally" blind children enrolled in school at that time showed: 24 percent were reported as totally blind; 16 percent as perceiving light only and approximately 60 percent as able to perceive more than light.[6]

Projection of these percentages to current enrollments reveals the probability that there are now more than 10,000 "blind" children in school who have sufficient vision (more than light perception) to be considered as potential readers of either print or of both print and braille. Selecting the most appropriate reading medium and educational placement for these students is difficult but of great importance to each child. In communities where separate facilities are maintained for blind and for partially seeing children this decision may determine whether the child will be educated essentially as a blind or as a seeing person. Some of the 10,000 or more children currently classified as legally blind who have more than light perception are able to function satisfactorily in the regular school program without special instruction. Many in this group, however, require educational aids and instruction by specially prepared teachers if they are to progress at a rate in accord with their ability. Some within this latter group will need to be educated primarily as blind children and others primarily as partially seeing children if placements are made in keeping with their most essential needs.

---

*Definition and classification problems in the field of vocational rehabilitation, as they apply to visually handicapped persons, currently are under study by the Subcommittee on Impairments of Visual Function of the Rehabilitation Codes being conducted by the Association for the Aid of Crippled Children under the direction of Dr. Maya Riviere. The National Institute of Neurological Diseases and Blindness is studying broad aspects of the problem and the Biometrics Branch of this institute is giving special attention to epidemiological studies of incidence, prevalence, and etiology of blindness and other severe visual defects as is the National Society for the Prevention of Blindness.

Mode of Reading

Educators have recognized for some time the necessity of using functional characteristics of visually handicapped children as criteria for classification and placement. Basic among important characteristics distinguishing blind from partially seeing children is the mode of reading best suited to each child. Increasingly, educational reference to a child as blind has come to mean that he reads and writes primarily by means of braille. Those "legally" blind children who, in the opinion of education specialists, demonstrate an ability to use print as their basic reading medium are generally classified as partially seeing.

But there is evidence to suggest that, among programs for visually handicapped children, widely diverse practices may exist in regard to the mode of reading children with limited vision are encouraged to adopt. Comparisons of the modes of reading of legally blind children whose residual vision exceeds light perception as reported by local and residential schools to the American Printing House for the Blind in 1960 disclose some revealing differences.[6]

Among the approximately 5,250 local school registrants with this much vision, about 82 percent were listed as reading primarily by means of print; 14 percent by means of braille; and 4 percent by means of both print and braille.

Among the more than 3,000 residential school registrants within this same range of vision, 29 percent were listed as reading primarily by means of print; 61 percent by means of braille; and 10 percent by means of both print and braille.

While several factors may contribute to the extensive differences found between local and residential school students in this respect, these differences are of such magnitude as to suggest the likelihood that conflicting opinions and practices are involved. Differences exist not only between local and residential school pupils within this range of vision, but also among different schools or programs within each of these groups. It is evident, for instance, that a few residential schools teach braille to all students, even though many are registered as having 20/200 visual acuity. Data from most residential schools, however, suggest that practices are more selective. Somewhat similar differences are found among local school systems, even at times within the same state or region.

Because of this diversity of opinion and the wide differences in practice, it would appear that reliance cannot be placed upon the mode of reading as a criterion for educational definition and program placement. The visual characteristics and educational needs of children with limited vision who read by means of either braille or print vary greatly. Therefore, use of the mode of reading to define and classify these children seems merely to move the problem from the visual acuity horn of the dilemma to another equally impractical one. It would seem that many children reading by means of braille have as much visual acuity as many others who use print as their primary mode of reading.

Visual Acuity

It is widely recognized that visual acuity alone is not a reliable criterion for defining or placing visually handicapped children. Reliance upon it as the most important single factor also is being challenged. In addition, many questions raised in connection with the use of present visual acuity designations center upon the fact that they do not correspond to the way children function in school. Yet, in many instances, administrators have used the visual acuity limits as the determining factor for placement rather than as a guideline. It frequently has been contended that wide variations are found in the needs of these children, particularly among those in the upper ranges of vision. Some educators maintain that continued use of these upper acuity designations is not in the best interest of children and is confusing to the public and to educators as well. Children falling within given visual acuity designations can be identified. But, if these visual acuity designations actually identify only children with visual limitations and not those for whom the limitations constitute educational handicaps, they are of very limited value in determining or predicting special program needs.

An example is the upper visual acuity limit of 20/70 which has been suggested as a guide for definition and placement of partially seeing children. It is now being contended that relatively few children with this much visual acuity require special consideration in their school program beyond that which can be easily arranged within the regular classroom. Repeated estimates have been made over the years that about one child in every 500 of the general school population may be expected to have corrected visual acuity in the better eye of 20/70 or less. However, a considerable number of specially prepared supervisors and consultants of visually handicapped children in charge of large state or local programs report that according to their experience as many as two-thirds or more of these children with 20/70 and less visual acuity are progressing well in regular classrooms without special instruction. They urge the retention of those visually limited children who make good progress in the general school program, but stress that routine checks should be made on their progress. On the other hand, evidence is beginning to accumulate that a few children with certain types of eye conditions whose visual acuity is better than 20/70 in the better after correction, tend to develop problems in school which may be related to difficulty in using their eyes effectively.[3] In general, however, it would appear that at this visual acuity level the exceptions may exceed the rule, resulting in some perplexing administrative problems. A thorough study of how appropriate the 20/70 visual acuity designation is and the development of additional criteria would seem essential to progress in this field.

Recent experience in teaching children with impaired vision is beginning to indicate that many, perhaps most, of those whose corrected acuity is found to approximate 20/200 (the upper limit of legal blindness) are able to become reasonably effective readers of print. Comparisons of data on degree of vision and modes of reading provided with the 1960 registration of children with the American Printing House for the Blind appear to raise further questions about the 20/200 visual acuity cut-off point.[6] The analysis conducted in the Office of Education included 4,400 children who were reported to have approximately 20/200 visual acuity. Almost 82 percent of these were registered as reading print, about 12 percent braille, and 6 percent both print and braille.

Included in this same analysis were data on 600 students reported to the American Printing House for the Blind as having approximately 15/200 visual acuity. Among this group it was found that about 67 percent were listed as readers of print, 27 percent braille, and 6 percent both. Study of data on 1,250 students whose visual acuity approximated 10/200 showed that 59 percent were registered as readers of print, 32 percent braille, and 9 percent both. The validity of these findings may be subject to question since there was no way to verify how precisely the eye information about the children was reported to the American Printing House for the Blind or how recently the eye examinations on which these reports were based had been conducted. However, since fairly large numbers of children were involved, it may be assumed that they are somewhat indicative of the true situation. They are grossly comparable to the findings on the visual nature and mode of reading of children in the study, Services to Blind Children in New York State.[2]

Refining Selection and Dismissal Processes

Educators are attempting to cope with problems associated with defining and classifying visually handicapped children in a variety of ways.

Local and regional advisory committees or councils of educators are being formed to guide special teachers and local directors in the selection, placement, re-appraisal, and dismissal of visually handicapped children. The needs of individual children are reviewed in the light of local, regional, and state facilities available to meet these needs. Group recommendations are made, thus relieving any one person of taking full responsibility for placement of a child in a special program or for withdrawing a child from such a program.

Eye report forms used by the schools are being revised to contain requests for specific and detailed information from eye specialists who examine children who are considered for placement in special programs. Forms which indicate the exact type of information needed usually save considerable time for both the school and the eye specialists. Information on diagnosis, prognosis, and measurements of near as well as far vision is usually included in these requests. Interest is growing, also, in requesting measurements of visual fields. Annual eye examinations are being required for children enrolled in some special programs to assure the availability of current information and to help prevent unnecessary loss of vision among those whose vision is already limited.

The functional characteristics of children with limited vision are being studied in an effort to select those whose visual limitations actually constitute educational handicaps. Information about intellectual ability is being reviewed and compared with that on scholastic progress. Children with visual limitations who are making appropriate school progress without the aid of special teachers are encouraged to remain in regular classrooms. Their progress is reviewed periodically by regular and special teachers or supervisors. When a discrepancy is found between the ability and the progress of a child with limited vision, a more thorough analysis is made of the nature of his problem. Special consideration is given those children with visual limitations whose eye conditions appear to be making it difficult or impossible for them to complete long reading assignments or other school tasks involving close eye work; to copy accurately material from texts, workbooks, or chalkboards; to those whose listening comprehension substantially exceeds that of their own silent reading; to those who tend to skip letters and words which look somewhat alike when blurred or distorted; and to those who may understand the basic principles involved in certain concepts such as those used in arithmetic but who make errors in the more routine computations, particularly when working with long columns of numbers. Thus, the child's visual acuity, which formerly constituted a major criterion for special placement, is coming to be considered as one among many factors.

General recognition is being given the fact that proper selection of the most useful reading medium (braille, print, or both) is very important to the child, requires special knowledge and skills on the part of the teacher, and is a choice confronting a sizeable number of children with limited vision. Teachers entering this field are being encouraged and even required in a growing number of places to study the needs and methods applicable to both blind and partially seeing children. The practicality of employing teachers properly prepared to serve both groups is being realized. This practice is helpful in many rural areas and in small and medium sized school districts where the number of visually handicapped children tends to be too small to justify special programs for each child. In such programs the needs of children with borderline vision can be studied intensively, over rather long periods of time, if necessary, by teachers prepared to teach reading by means of either braille or print. It is suggested that these teachers are less inclined to favor one or the other mode of reading. The need for making an early placement of children in either a special program for blind or for partially seeing children is removed.

New Knowledge

Educators in this field as in other areas of special education are faced with the necessity of developing a new body of scientific knowledge if realisitc definitions and guidelines to educational classification are to evolve. Teachers and supervisors in this special area have proved to be receptive to new ideas and the application of these to educational practices has enabled them to set patterns for others to follow. Their present concern for developing and refining definitions and placement practices once again reflects the thinking of forward looking people.

Search for agreement among experts in this field should continue. Local and regional surveys based on precise information of known validity about the primary diagnosis and the effect of the visual disabilities on both near and far point visual acuity of children in special programs are needed. Such surveys, replicated in various places by state and local educators, would be particularly helpful if visual acuity designations were to be sharpened and their use for purposes of educational definitions retained. The seemingly wide differences in modes of reading among students with similar degrees of vision appear to be so pronounced that reasons for them should be explored. Controlled studies seeking answers to many related questions should be undertaken. What factors other than visual acuity tested beyond the reading distance are important in determining the mode of reading performance of children with very low vision? Does the average child whose visual loss is associated with a particular condition such as nystagmus tend to be a more likely candidate for special education than one with a different condition but a similar degree of visual acuity? Is he more likely to succeed in reading by means of braille or by means of print? How extensively is large print material used by children with visual limitations? Which among them must rely upon it for their independent reading? Does the introduction of braille as the first trial reading medium result in a loss of the opportunity for young children to develop print reading skills and use of residual vision at an age when the chance for this development is optimum? Or does the introduction of print as the first trial reading medium to children with inadequate vision result in a loss of the opportunity for them to develop adequate skill in reading by means of braille? What constitutes a good trial climate and an adequate trial period for most of these children?

More children with impaired vision are enrolled in the nation's schools than ever before. Predictions of future enrollments are being adjusted upward as it now appears that larger numbers of visually handicapped children resulting from the general population increase may be following the "wave" of those whose limited vision or blindness was caused by retrolental fibroplasia. The opportunity and need to study and improve methods and practices pertaining to the educational definition and classification of these children is at hand.

REFERENCES

1. "Conference on Educational Definition and Classification of Visually Handicapped Children and Youth." Section on Exceptional Children and Youth, U.S. Office of Education, Summary Report (unpublished report).
2. Cruickshank, William M.; Trippe, Matthew J., Services to Blind Children in New York State. Syracuse University Press, 1959.
3. Eames, Thomas H., "Visual Handicaps to Reading," Journal of Education, Vol. 141, No. 3, February 1959.
4. Fonda, Gerald, "Definition and Classification of Blindness with Respect to Ability to Use Residual Vision," New Outlook for the Blind, Vol. 55, No. 5, May 1961.
5. Foote, Franklin M.; Bryan, Dorothy; Gibbons, Helen, Education and Health of the Partially Seeing Child, Fourth edition, Columbia University Press, 1959. p. 17.
6. Jones, John Walker, Blind Children, Degree of Vision, Mode of Reading, U.S. Department of Health, Education and Welfare, Office of Education, Section on Exceptional Children and Youth, Bulletin #24, 1961.
7. The Pine Brook Report. New York: American Foundation for the Blind, 1954, p. 26.
8. A Teacher Education Program for Those Who Serve Blind Children and Youth. New York: American Foundation for the Blind, 1961. p. 9.

TOWARD A FUNCTIONAL DEFINITION OF BLINDNESS

by

Milton D. Graham, Ph.D.

EDITOR'S NOTE:

This article is reprinted from THE NEW OUTLOOK FOR THE BLIND, October 1959.

Dr. Graham is Director of the Division of Research and Statistics of the American Foundation for the Blind.

A recent announcement by the federal government makes it necessary to evaluate critically two definitions of blindness. On June 12, 1959, the Department of Health, Education and Welfare released to the press an announcement that said in part:

> Not counting military personnel or civilians in mental or other long-term institutions, the American people had, all told, about 24,000,000 impairments during the twelve months July 1957 through June 1958.... This was the finding in the latest of a series of published statistical reports issued by the U.S. National Health Survey of the Public Health Service.... Blindness--defined in this report as the inability to read ordinary newsprint even with help of glasses--was reported for an estimated 960,000 people, a rate of 5.7 per 1,000 persons. In addition, 2,064,000 people were reported to have visual impairments less severe than blindness, the rate being 12.3 per 1,000.... The figures are derived from the continuing nationwide household interviewing conducted for the Public Health Service by the U.S. Bureau of the Census with a representative sample of the population. The information recorded about individuals is confidential and only statistical totals are published.
>
> The new report is Impairments, by Type, Sex and Age, United States, July 1957--June 1958, Public Health Service Publication No. 584-B9. Copies are for sale by the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at twenty-five cents a copy.

This report of the U.S. National Health Survey,[1] which will undoubtedly receive wide circulation, on the face of it seems to contradict the definition of blindness recognized in Title X (Grants to States for Aid to the Blind) of the Social Security Act, a definition that was recommended by the Section of Ophthalmology of the American Medical Association. Using this definition, and a detailed method of calculation, Hurlin[2] arrived at an estimated rate of prevalence of blindness for the total United States in 1957 of 1.98 per 1,000 population. Applying this rate to the estimated population of continental United States in 1959 gives an estimate of about 350,000 blind persons.

This seemingly wide discrepancy is in fact not contradictory when the different purposes of the two definitions are examined. The definition recommended by the Bureau of Public Assistance is an economic definition of blindness. The National Health Survey definition implies a functional definition of blindness. One is concerned with the economic condition of blind persons; it is deeply rooted in the depression of the 1930s and the social security philosophy of meeting need. The other is concerned with public health criteria and the very recent emphasis on the total performance of an impaired individual.[3]

Before pointing out the very important implications of these two approaches, it needs to be said that there has never been a scientifically conducted survey of the blind population. Hurlin said in 1938: "The enumeration of blind persons in connection with population census was not satisfactory and could not be relied upon as producing dependable statistics of the blind."[7b, p.74] The estimates of the blind population and their characteristics from 1830 to 1930 were provided by the ten-year census of the country. Of the eleven such censuses, the census of 1880 is acknowledged as probably the most thorough and accurate with respect to the blind population.[4, p.13] It established the rate of one per 1,000 generally used until 1938.[5]

The reasons for the gross inaccuracies of past estimates have been frequently set forth.[6] Among them is the fact that certain segments of the blind population have generally been underestimated: the very young, the females under thirty, the institutionalized, those economically independent, and those wholly dependent on relatives or friends. These underestimations were generally due to faulty techniques of data-collection, which was often done by correspondence with persons whose names were provided by agencies. In the early 1930s, when there was a great deal of concern about standardizing the economic definition of blindness,[7] recommendations were made about the varying degrees of blindness "to indicate differences which have a real significance in determining the tasks which an individual can perform."[8]

Inevitably, with attention being directed toward purely medical findings, there began to be questions about the efficiency with which the partially sighted person used what vision he had left. This concern with visual efficiency became more pronounced during World War II when many disabled persons were hired in war plants; their excellent performance gave impetus to rehabilitation services and optical aids programs. The enactment of the Barden-La Follette Act of 1943 (Public Law 113, Seventy-eighth Congress) established many new services in rehabilitation and training and encouraged the revealing of hitherto undisclosed portions of the blind population.[9] Also, Sanders' study of 1943[10] estimated that two-thirds to three-fourths of all blindness was preventable; he spoke, too, of the positive gains to be realized through vocational guidance and training, as well as the occupational and social readjustment of the traumatically blind. He was one of the first to plead that prevention and rehabilitation "will net valuable social returns."

Studies by ophthalmologists on the effectiveness of optical aids in bringing up low vision to usable visual efficiency began appearing in the 1950s. Fonda,[11] Esbin,[12] and others told of the great technical advances made in low-vision aids. The most recent study (at this writing awaiting publication in the American Journal of Ophthalmology) has been made by Dr. Richard Hoover of Baltimore, Maryland.[13] He reported on the 841 patients in seven low-vision clinics, with data on type of patient, eye pathology, visual acuity, visual need, and success of increasing acuity with visual aids. All patients had sought the clinic; median length of blindness was eight to twenty years; the group was predominantly male. Most were able to travel without a companion and listed reading as their primary visual need. One group with certain eye conditions seemed to be more amenable to improvement of acuity, with an average of 52 percent of the cases improved. The other group average was 36 percent. For both groups the rate of onset of poor vision was over ten years. This suggests that earlier treatment might have yielded much greater returns.

Two characteristics of the population of the Hoover report need to be emphasized: 1) the patients sought help themselves, and 2) their rate of onset (more than ten years) probably meant that they had made some psychosocial adjustments to their blindness. This latter factor has had to be seriously contended with by others: "The patient's motivation has been found to be one of the determining factors in his successful use of optical aids," Esbin said in 1957.[12, p.4] "Motivation and intelligence are the paramount factors for a successful correction," Fonda said in 1956.[11, p.3] The Veterans Administration Program Guide on Blind Rehabilitation[14] says:

> It is of very great importance in the case of the partially seeing patient to determine exactly what he sees and under what conditions.

This cannot be truly portrayed by ophthalmological measurement alone. Actual experience is also necessary with the patient in action. Since all visual difficulties are highly traumatic, a great deal of tact and time are required in doing this, and the individual approach to the individual patient is of very great importance.

In the Pine Brook Report, published by the American Foundation for the Blind in 1952, the term "psycho-visual efficiency" was used for the first time to describe motivational factors as well as medical factors that make for efficient use of residual vision.

All of these developments were within the limits set by the economic definition of blindness, i.e., a condition correctible to 20/200 or less. The National Health Survey's functional definition of blindness has no such restrictions: if a person functions as a person without normal sight (i.e. ability to read newsprint), he is from this viewpoint blind, whether or not he considers himself a blind person. Hurlin, in his 1953 study, recongized that many persons within the margin of economic blindness as defined would not be enumerated as such:

> Many persons who have such marginal defects do not consider themselves as blind and therefore do not come to the attention of the enumerator or case finder in any practicable procedure of enumeration or registration of blind persons. Thus the reservation should be made that the present estimates are presumed to represent persons who are blind within the definition of economic blindness and who recognize an effective handicap, or those who are effectively visually handicapped to this extent.[2, p.7]

The U.S. National Health Survey has undoubtedly included in its estimated figure a very large number of persons who do not recognize as blindness the handicap that prevents them from reading newspaper print even with glasses. For example, there is reason to believe that the large number of housewives (326,000) called blind by the National Health Survey probably need only proper optical aids. It is also likely that many of them could have their visual acuity improved sufficiently to read newsprint if their reluctance to wear glasses were overcome. This can be fairly called a national health problem.

What now needs to be done is to explore the implications that the functional definition of blindness has for work in the field of services for blind persons. Research should be undertaken to relate the two definitions to each other in a completely meaningful way. If persons designated as blind in the functional sense could be located and questioned further, in lay language, as to the nature of their handicap and their appreciation of it, much useful insight might be gained. Such persons might well at first resist an ophthalmic examination with its implications of impairment. The immediate task appears to be to devise in lay language a reasonably accurate approximation of the medical terms used in defining economic blindness. As a beginning, the work of the Committee on Central Statistics of the Blind of the 1930s[15] needs to be subjected to experimental testing. The experience of ophthalmologists with low-vision patients who have successfully increased their visual efficiency needs to be drawn on for guidance, especially the data collected by Hoover which needs to be carefully studied.

One thing is certain: the definition of blindness which has been used in the National Health Survey must be dealt with. It is best to get on with the work that will explain it and relate it to our national health needs in the field of blindness.

REFERENCES AND NOTES

1. U.S. National Health Survey. Origin and Program of the U.S. National Health Survey. Health Statistics. Series A-I. Public Health Service Publication No. 584-A1. Washington, D.C., Public Health Service, May 1958.

See also:

______ *The Statistical Design of the Health Household-Interview Survey*. Health Statistics. Series A-2. Public Health Service Publication No. 584-A2. Washington, D.C., Public Health Service, July 1958.

______ *Concepts and Definitions in the Health Household-Interview Survey*. Health Statistics. Series A-3. Public Health Service Publication No. 584-A3. Washington, D.C., Public Health Service, September 1958.

Linder, Forrest E., "Organization of the National Health Survey." *The American Statistician*, Vol. 13, No. 3, June 1959, p. 7.

2. Hurlin, Ralph J., *Estimated Prevalence of Blindness in the United States*. New York, American Foundation for the Blind, 1953. 15 pp.
3. The introduction of "comprehensive medicine" and recommendations of the Bayne-Jones report indicate the trend: *The Advancement of Medical Research and Education through The Department of Health, Education and Welfare*. Washington, D.C., U.S. Government Printing Office, June 27, 1958.
4. *The Blind Population of the United States, 1920*; A Statistical Analysis of the Data Obtained at the 14th Decennial Census. Washington, D.C., Government Printing Office, 1928. 191 pp.
5. "Estimates of Blindness in the United States." *Social Security Bulletin*, March 1945, pp. 17-18.
6. Particularly in *Blind Population 1920*: Sanders, Hurlin (1937) and McKay (1931).

   See also:

   Britten, Rollo H. "Blindness as Recorded in the National Health Survey..." *Public Health Report*, Vol. 56, No. 46, 1941, p. 17.
7. (a) Berens, Conrad, "Standardization of Statistics on Causes of Blindness." Paper presented to Pan American Medical Association, March 24, 1933.
   - (b) Hurlin, Ralph G., "Recent State Surveys of the Blind." *Outlook for the Blind*, October 1937, pp. 119-23; February 1938, pp. 6-11.
   - (c) McKay, Evelyn C., "Uniform Statistics of the Blind." *Proceedings* of American Association of Instructors of the Blind Convention, 1934.
   - (d) Jackson, Edward, "Blindness in the Census," *American Journal of Ophthalmology*, 1930, pp. 155-56.
8. "Contribution of Statistics to the Prevention of Blindness." National Society for the Prevention of Blindness, Publication 164, December 1934, 35 pp.
9. Lende, Helga, *Federal Legislation Concerning Blind Persons in the United States and Insular Possessions*. New York: American Foundation for the Blind, 1958, p. 19.
10. Sanders, Barkev S., "The Blind--Their Numbers and Characteristics." *Social Security Bulletin*, October 1943, pp. 17-26.
11. Fonda, Gerald, "Report of 500 Patients Examined for Low Vision." *AMA Archives of Ophthalmology*, August 1956, Vol. 56, pp. 171-75.
12. Esbin, Leo, "The Optical Aids Service of IHB" (unpublished). Paper to Pan American Association of Ophthalmology, April 8, 1957.
13. Hoover, Richard, in a forthcoming article (1959) in *The American Journal of Ophthalmology*.
14. "Evaluation of Blinded Patients." In *Program Guide*, Office of the Chief Medical Director of the Veterans Administration, August 15, 1958, p. 13.
15. McKay, Evelyn C. "The Work of the Committee on Central Statistics of the Blind." *Outlook for the Blind*, June 1931, pp. 161-65.

XII

ACTIVE ENERGY RADIATING SYSTEMS: THE BAT AND ULTRASONIC PRINCIPLES II
ACOUSTICAL CONTROL OF AIRBORNE INTERCEPTIONS BY BATS

by

Frederic A. Webster
Research Consultant
Cambridge, Massachusetts

EDITOR'S NOTE:

This paper was read at the International Congress on Technology and Blindness, 1962, and will be reprinted in the Proceedings of that Congress.

This work was performed in part under a subcontract with MIT Lincoln Laboratory, which is operated with support from the U.S. Army, Navy and Air Force.

Why should a paper on airborne interceptions by bats form part of a symposium on Man-Machine systems and Mobility Devices for blind persons? Why bats? Why interceptions? The broad reason why so many symposia on blind guidance include discussions of the general techniques of bats is perhaps fairly obvious: bats are acoustically guided creatures--and very successfully so. They must, therefore, be capable of extremely proficient acoustical orientation. Man might learn a lot about effective acoustical guidance by a study of their methods. But why the focus on interceptions of airborne targets? The reason again is very straightforward. Airborne interceptions constitute the focal point around which a major portion of the bat's techniques have developed: insectivorous bats, after all, survive in large measure by the capture of flying insects. In seeking a truly comprehensive grasp of the bat's methods and the rationale behind them, the central components in their evolution cannot be by-passed.

The structure of the present paper was thus dictated by the following major considerations.

1) Using auditory reference alone (or virtually so), bats execute almost preposterously quick and accurate maneuvers, often under severe constraints imposed by complex physical surroundings. They do this with equipment that is, perhaps, thousands of times smaller than the corresponding equipment of the human auditory system; vastly smaller still than any effective artificial system. Their methods and their mechanisms must, therefore, warrant thorough study by those seeking oriented guidance of human beings or of artificial systems by nonvisual means.

2) Tests have shown, however, that direct conversion of the more obvious features of a bat's signal system to the frequency range of human hearing does not in itself provide an adequate basis either for interpretation by the human auditory system or for evaluation of the environmental features essential in human applications. More must be known about how the human auditory system deals with problems akin to those of the bat; about how the auditory system of the bat deals with the information it receives, and about the interrelations among emitted signal, physical problem, auditory analysis, and motor control in the bat's situation.

3) There are many avenues of approach to the bat's system: histological, neurophysiological, ecological, psychophysical, and behavioral, among others. Behavioral analysis of the bat's performance on central problems of its survival is certainly a vital one. The present discussion undertakes an introductory survey of the bat's performance and techniques in the capture of its prey. As is to be expected, however, such analysis leads to a regress: the receding succession of questions that deal with how the bat's system came to be evolved in its present form. In the evaluations of its quickness, precision, and reliability we learn much about its remarkable performance and how this is achieved; but in its flaws, its errors, and its inadequacies we gain additional insights into the forces that make it what it is. The present paper attempts to put the bat's methods and accomplishments in this perspective.

INTRODUCTION

Insectivorous bats equipped with a computational system little larger than the tip of a pencil, use acoustically triggered mechanisms to guide their interceptions of insect targets. They do so with a quickness, precision, and infallibility that often leaves our largest and fastest electronic equipment far behind. Sometimes all the insects to be caught are edible, readily detected, and flying slowly in an unobstructed area. Such pursuits are easy. At other times, however, the interception situation is vastly more complex and difficult. The insects may be as small as one-fifth milligram (e.g., gnats) or as elusive as the deftly evading noctuid moths; some may be distasteful or dangerous; and often the areas in which the insects must be caught are intricately laced with foliage, or lined with destructive projections such as thorns and twigs. How can a bat, under such precarious conditions, engage in a thousand pursuits a night, perhaps with over 90 percent success--even achieve interception rates that reach two per second--and yet survive unharmed for 20 years?

History reveals a strange lack of imagination and initiative in dealing with this intriguing problem.[3, 8] The outstanding early work was done by Lassaro Spallanzani and several contemporaries, starting about 1793. Spallanzani, for example, discovered that bats which had been blinded found their way back to their roosts as well as did non-blinded bats, and that they appeared to catch just as many insects. Moreover, Rees' Cyclopaedia of 1819, referring to experiments done in the late 1790's, says that according to "Professor Jurin of Geneva...neither the touch, nor ear, nor smell, nor taste is...sufficient to supply the want of sight; but from some anatomical investigations of these animals, he concluded that a very large proportion of nerves is expanded on the upper jaw, the muzzle, and the organ of hearing; and these appeared to him, in a great degree, to account for the extraordinary faculty..."[26] Before 1800, in other words, the ears and mouth were jointly implicated in the mechanisms of orientation and pursuit. Moreover, the relevant observations were publicly available. Yet for almost a century and a half, in an era of great scientific curiosity and growth, no further progress of account was made.

Long-delayed recognition of the fact of sensory detection beyond the range of human sensitivity, together with instrumentation for the relevant measurements, finally reopened the door to the bat's orientation secrets. But it took an imaginative undergraduate at Harvard College to initiate the crucial tests. Shortly before the Second World War, Donald R. Griffin, with the collaboration of Robert Galambos, began a systematic study of the bat's ultrasonic signals.* These investigators did not, however, study pursuit behavior at that time. Rather, they studied another major area: the avoidance of obstacles.[4, 10] Such behavior was more easily brought into the laboratory and much more readily adapted to quantitative evaluation. Their work amply demonstrated that ultrasonic mechanisms alone accounted adequately for all the measured obstacle avoidance.

---

*Griffin notes with respect that the Dutch zoologist, Sven Dijgraaf, determined independently of the work being done by himself and Galambos--and with his unaided ears alone--that the faint audible component of the bat's orientation signals was directly related to obstacle-avoidance. By testing the effects of ear-plugging, mouth-blocking, and sensory denervation of the wings, Dijgraaf established that echolocation was the bat's means of orientation--and did so with no significant instrumentation beyond that which had existed for centuries.[8, p.76]

Actually, the avoidance of specific obstacles is part of a somewhat branched continuum of oriented behavior. At one end of this continuum are the general surrounding configurations which shape the bat's over-all flight path. Here, for example, are the leaves and small branches of trees which constitute specific obstacles by themselves, but under many conditions reach a density and extent which a bat evaluates as a total grouping. Here it is the total configuration rather than the specific obstacle that constrains the bat's direction of flight. At the other end of the continuum are small, discrete, moving objects--namely flying insects--which are to be pursued and caught. What about a falling leaf? Such an object is well down the continuum from a tree, or even from the end of one its branches. Yet a leaf is ordinarily not as small as an insect, nor does it have the same attributes of motion. Is it to be avoided or pursued? As will become evident below, categorical answers to such questions are not possible, for the zone of transition between obstacles and food targets is large, and many factors may influence a bat's decision.

If we assume for the moment that evolutionary forces have committed the bats under discussion to survival by acoustically guided captures of flying insects, we must next look for the elements that may have shaped the bat's methods and techniques. In other words, we must gain a frame of reference defined by the basic nature of the bat and by the tasks it has to perform. First of all, we must inquire into the nature of the bat itself: its physical structure, its operating limits in terms of flight-speed, reaction time, maneuverability, and so on. We must also explore the nature of its signals, echo-reception devices, and processing mechanisms. Second, we must discover how it actually goes about the maneuvers by which it survives, how it decides what to catch and what to avoid, and how it governs the interception procedures it uses. Third, we must learn something about the targets themselves: their size, their reflective changes as a result of wing action and relative orientation, their flight velocities and flight patterns; also, special attributes that may modify the bat's problems of identification, selection, and pursuit. Finally, we must note effects of the surrounding situation: how, for example, the bat deals with the intricate spatial relations that often constrain the course of interception. All such questions obviously break down into innumerable subquestions. Although answers to some of these subquestions are pretty well known and will be illustrated below, many are virtually unexplored; and certainly all must be answered within the broad frame of reference given by the bat's basic nature and by the total nature of its task.

GENERAL NATURE OF BATS, THEIR SIGNALS, AND THEIR INTERCEPTION PROBLEMS

DOMINANT CHARACTERISTICS OF BATS

Physical Characteristics and Their Implications

Physically, the insectivorous bat of the temperate regions is small (body length roughly 5 to 8 centimeters), light (roughly 5 to 15 grams), and flexible (see illustrations below). Such properties obviously adapt it well to its particular mode of life. They permit it to maneuver fast and respond quickly. The low inertia of the bat's physical components permits high acceleration of structures such as the wings; and its lightness is such that the air readily provides the resistance required for rapid aerial maneuvers. Moreover, neural conduction takes less time over short pathways. Such properties, however, also dictate in large measure the maximum admissible size of the analytical, evaluating, and integrating systems. Were a bat's brain to become larger, its total weight would increase and its possible maneuverability and speed of response would go down. The bat would thus be forced to rely on interceptions predicted further in advance. But the complexities of long range prediction tend to multiply enormously. In the bat's situation, they would call for disproportionate increases in the powers of analysis and evaluation. Varied, but simple, tactics of evasion and deceit by the various members of the insect world might produce a virtually insurmountable array of problems in selection and prediction. To make matters worse, the increasing size of the bat would enhance its nutritional needs and once more aggravate the problem. Some bats appear to have found a way out of this dilemma by adapting to new foods: fruit, nectar, and fish, for example. In the present discussion, however, we are concerned with bats that have remained insect eaters. It is clear that such bats use their natural attributes to excellent advantage; they have not only survived long in the course of evolution,* but they also live long as individuals.

Some Other Attributes of Bats

Questions about speed, maneuverability, and reaction time will be partially answered in the illustrations presented later. By way of preliminary comment, it can be said that flight speeds vary from 0 ft/sec for hovering bats like Plecotus (as, for example, during the exploration of some detail of its surroundings, see Figure 1), to perhaps 35 or more ft/sec for the red bat, Lasiurus borealis, during pursuit. In the laboratory, flight speeds normally range from about 8 to 20 ft/sec (roughly 2 to 6 meters/sec). Maneuverability is astonishing. Figure 2, for example, shows a wild red bat which in roughly one-third of a second of pursuit rolled onto its back, dove, rolled upright, and captured a moth that was spiraling toward the ground. Response times have not been systematically measured, but high speed films suggest that observable reactions to unexpected events may sometimes take place in as little as one-thirtieth of a second. The remarkable and violent maneuvering of many insects demands quick appreciation of trajectory and a rapid response to sudden shifts of the target's path.

General Nature of Bats' Signals

From what has already been said, it is clear that the echolocation system of bats has extremely severe demands upon its capacities. For example, it must allow a very rapid rate of data input; it must permit excellent resolution of detail, and it must facilitate extraordinarily quick handling of rapidly shifting spatial relations. For a bat's interceptions to be successful, in other words, the evaluations made by the bat must not only be very quick but they must often be extremely precise. Clearly the bat's signals must provide for efficient sorting of input data at high data rates, excellent resolutions of detail, and remarkable resistance to confusion in complex situations.

Interestingly enough, different bats have evolved rather different signal structures. Indeed the only features common to all are: (1) pulsed form, (2) high average frequency (mostly 20 to 120 kc/sec), (3) variable duration, (4) variable repetition rate (duty cycle varies from roughly 2 percent to 90 percent in different bats and different situations), and (5) sinusoidal or harmonic structure of the carrier (as opposed to a click or noise structure). Most outstanding among these features, perhaps, are: (1) the high frequencies of the carrier and (2) the variability of the different functional units that make up the signal.

Among the more important differences the following are conspicuous. Certain bats, notably the Old World Horseshoe bats, emit very long pulses (up to 50 milliseconds or more) which are extremely constant in frequency over most of their duration. Other bats, by contrast, emit pulses which seldom exceed 3 milliseconds in duration. From these figures it is immediately apparent that certain bats must be guided chiefly by echoes which are received while the pulses are being emitted, while others must be guided primarily by echoes received during the quiet intervals between pulses. Moreover, since

---

*Bats appear to have remained basically unchanged for about 50 million years (see, for example, 8, p. 6).

Figure 1. Plecotus townsendii hovering. Plecotus bats are noted chiefly for their very large ears and associated low-intensity signals. Another striking feature is their capacity to hover, somewhat after the fashion of the hummingbird. While hovering a half-dozen inches from a surface, these bats can apparently make certain detailed evaluations of configurations on the surface. They detect stationary insects and commonly are able to make precise localization of mealworms held in the fingers. They have also been observed to initiate pursuit of insects flying very close to a surface. Pulse durations while hovering are of the order of one millisecond.

the long pulses often have a very gradual beginning and ending, as well as almost no modulation, they contain virtually no intrinsic time reference, whereas the short pulses normally incorporate either a very rapid frequency sweep, from high to low, or they include a variable harmonic structure. Either of these can provide an effective time reference. Enormous variations in signal intensity are also seen among the different bats.[8,13,20] A microphone placed 1 foot in front of the point of signal emission may show intensities as high as 105 db (re 0.0002 dynes/cm^2) for the larger Horseshoe bat and as low as 60 db for Plecotus, or less than 55 db for the whispering bat Carollia. Frequency range, as already suggested, also differs greatly from bat to bat; moreover, it may shift markedly during the course of maneuvers by a given bat, though such shifts also vary from bat to bat. Despite these and other variations, all insectivorous bats seem capable of very remarkable speed and precision in the use of their signal indications.

To understand how a bat uses its signals to guide its interceptions of insects, we must first know how a bat goes about intercepting and capturing its targets. But we

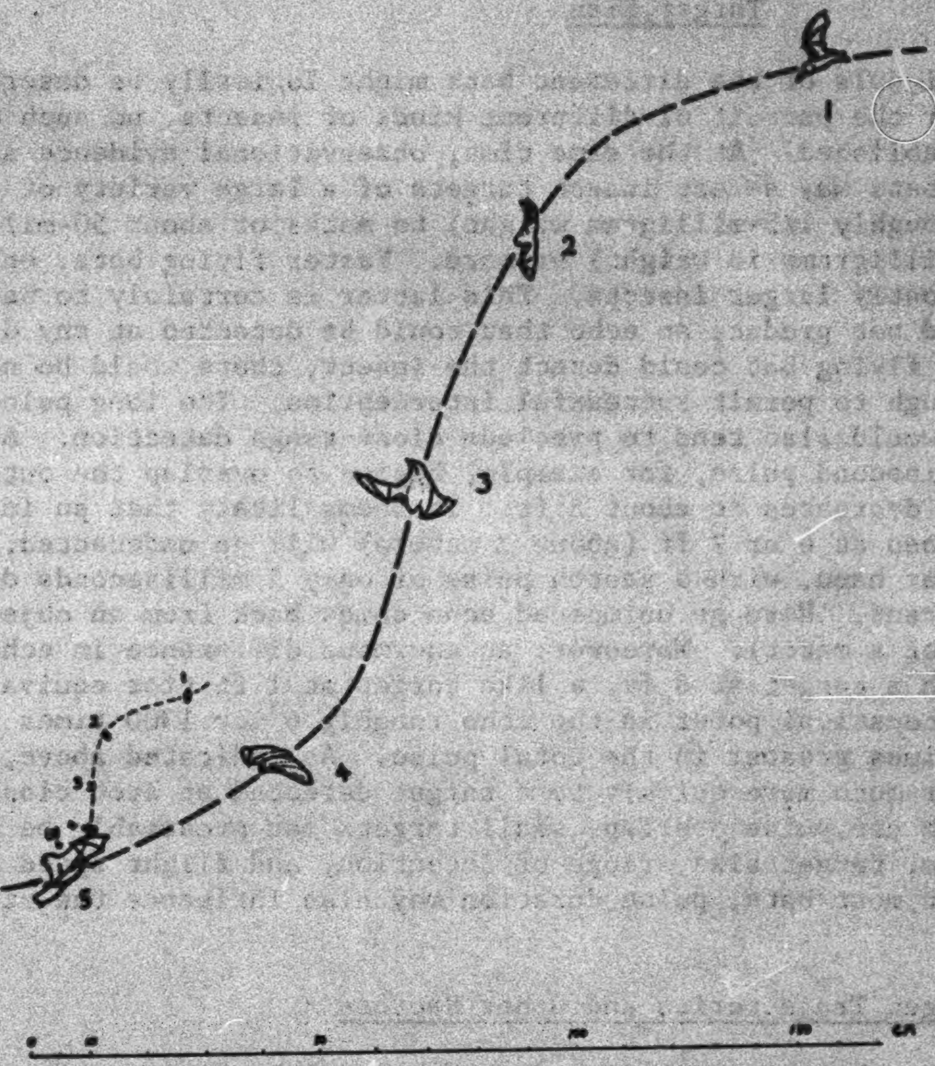


Figure 2. Capture of Downward Spiraling Moth by the Red Bat *Lasiurus borealis*. Approaching at a speed of about 20 feet (6 meters) per second, the bat rolled onto its back, dove, righted itself, and captured the moth--all in about a third of a second. Significant also is the fact that this interception was so close to the ground (about three feet) that the form of the interception had to be shaped to the configuration of surface obstacles. (This figure is traced from a multiflash sequence with a flash rate of about 10/second. Except where noted, subsequent multiflash pictures were made at this rate, plus or minus about 1/2. Corresponding pictures of bat and target are normally numbered, with the larger number representing the bat, and the smaller number the target.) This picture was made in collaboration with A.E. Treat.

still have to go back another step. The reason why a bat catches as it does derives from the nature of the targets it has to catch and from the characteristics of their flight paths. Before investigating the details of the bat's techniques, therefore, something should be known about the nature of the targets and their actions.

SOME PROPERTIES OF THE BAT'S TARGETS

Target Size

While the varying signals of the different bats might logically be described in erms of requirements for the pursuit of different kinds of insects, no such clear-cut ategories have been established. At the same time, observational evidence suggests hat many slower flying bats may select insect targets of a large variety of sizes, from -millimeter gnats (of roughly 1/5-milligram weight) to moths of about 50-millimeter ing span (roughly 200 milligrams in weight) or more. Faster flying bats, on the other and, appear to select mostly larger insects. This latter is certainly to be expected. very small insect would not produce an echo that could be detected at any distance. hus, by the time a fast flying bat could detect the insect, there would be no chance or a maneuver quick enough to permit successful interception. The long pulse length of ome of the faster bats would also tend to preclude close-range detection. An echo eturning from a 10-millisecond pulse, for example, begins to overlap the outgoing pulse hen the object distance decreases to about 5 ft. It seems likely that an insect too mall to give usable echoes at 6 or 7 ft (about 2 meters) will go undetected, or certainly nevaluated. On the other hand, with a search pulse of only 2 milliseconds duration, the ituation is quite different. Here an unimpeded echo comes back from an object as close s 1 ft away (one-third of a meter). Moreover, an enormous difference in echo strength xists. As compared with a target at 6 ft, a like target at 1 ft (for equivalent signal requency) produces an acoustical power in the echo roughly 6^4 or 1300 times greater per illisecond, about 250 times greater in the total pulse. As indicated above, the slower lying bat could maneuver much more quickly to a target detected at such close range. ven for those bats which use pulse overlap, small targets can presumably be detected nly close at hand. Thus, target size, range of detection, and flight speed must be losely related; and, for most bats, pulse duration may also influence the size of targets selected.

Target Trajectories and Other Factors

Size, however, is not the only important attribute of a bat's targets. Flight speed, acceleration, and pattern of maneuver are equally relevant. Though the flight speeds of night flying insects tend to be considerably less than the flight speeds of bats, many insects are capable of rapidly accelerated dartings and dives; some execute abrupt and unpredictable changes in flight direction, while others carry out complex and varied evasive tactics.

Presumably a significant relation exists between insect size and violence of maneuver. Fruit flies, for example, would not be expected to reach the speeds, nor to exhibit the complexities of maneuver, noted in many of the larger insects such as moths. This situation may well provide a convenient exchange relation. The bat, in other words, may be free to choose between simple catches frequently repeated or difficult catches achieved at greater intervals and with greater effort. With small targets, a bat can normally expect lower velocities and a smaller chance of rapid maneuver. This presumably simplifies the interception procedure and the technique of catch. To avoid unnecessary effort on such small insects, a bat might use techniques producing rapid captures but not certainty of catch. The bat's objective here would be to achieve the most rapid possible succession of likely catches without wasting excessive time or effort on any one. With larger targets, the situation is different. In terms of fuel and other essentials gained, the value of such a catch may be 100 or more times greater. Much more effort and time per catch are thus warranted. Since larger insects also may execute more baffling maneuvers, much greater effort may be needed to achieve reasonable probability of catch. It is also likely that some insects are harmful or obnoxious. Since this is much more likely to hold for the large insects, careful selection and evaluation of individual larger targets may become essential. Just how a bat plays its hand so as to achieve the highest probability of gaining essential nutrition with the least effort and minimum risk is a problem that may turn out to be very complex. Certain elements in the picture will become evident in the illustrations below, but many facets of this intriguing problem remain to be discovered.

THE BAT-MOTH BATTLE

Evolutionary Nature of the Bat-Moth Battle

Possibly the most significant and arresting of all the bat's interception problems are those which relate to the so-called "bat-moth battle." Their significance derives in considerable measure from the long evolutionary history which must have produced the intricate tactics and countertactics now in evidence. That certain moths, notably the noctuids and geometrids, respond to the sounds of approaching bats was suspected long before actual measurements of the moths' tympanic responses were made.[29, 34, 37] The extent to which the techniques and tactics on the two sides interact, however, has only recently come to light. Certain general features of the situation are worth noting. The insects have many more individuals and these individuals are produced at much more rapid rates. Moreover, there are many more kinds of insects than bats and each kind of insect may have developed different properties which serve to complicate and confuse the bat's evaluations. Being smaller and lighter than bats, yet large enough to attain significant speed, many of them can maneuver with remarkable quickness and acceleration. As individuals, however, the insects possess little adaptive capacity. Whereas an individual bat may live to outwit a particular insect, the individual insect can make little progress in adapting to the pursuit tactics of the bat.

But the bats have their problems too. For example, if the bat is to survive for its normal life expectancy, which is often 10 to 15 years or more, it cannot take serious risks. For instance, were it to pursue its target into the twigs of a tree it would be very likely to tear its wings and not survive for long. Bats, moreover, must contend with a great deal of variety among the different members of the insect world and with corresponding diversities in their behavior. The bat, must, therefore, gain its advantage through individual skill and through precise and rapid evaluation of specific situations. At the same time, the very small size of the bat's brain must severely limit the extent and complexity of its learning. Learning and adaptation of individual bats is probably well tailored to the more critical aspects of the echolocation problems it faces. It is thus not surprising that, in the face of relatively simple-seeming artificial problems, bats often appear astonishingly stupid; yet, in the solution of complex natural problems, they commonly seem incredibly capable and adept.

The Moth's Detection of Sounds from Bats

In recent years much has been discovered about the moth's mechanisms of hearing.[27-32, 34-37] Outstanding features of the moth's acoustic system are: (1) its great sensitivity, (2) its simplicity, and (3) its rough matching to the wide band of frequencies emitted by bats. The moth's sensitivity to bat sounds is such that signals from a bat 100 or more feet away can readily be picked up from the moth's tympanic nerve and made audible to human listeners.[31] But the tympanic nerve on each side is remarkably simple: it normally contains only two sensory fibers (designated A fibers)--one that is highly sensitive and one that is about 20 db less so. The frequency range of a moth's hearing is also remarkable. Responses are obtainable from sounds ranging from 3000 to over 150,000 cycles/second. Other important features have also been noted.

But how does a moth use its bat-detection system? A few specific observations have been made by Roeder[29] and others, but, for the most part, existing evaluations are still largely guesswork. Some of the more obvious things a moth might determine are: distance of the bat (but probably only the nearest bat if several were present), direction (again probably only of a single bat), phase of interception (perhaps by judgment of intensity or pulse repetition rate), and conceivably proximity to protective objects (as, for example, grass or leaves where the moth can hide). That a moth can often judge the direction of an approaching bat has been demonstrated experimentally by Roeder.[27] Indications are that a moth tends to turn so that its axis is parallel to the bat's and thus produces minimum echoes from the bat's signals. This action occurs, however, chiefly when the bat is at some distance. At close range, the moth seems capable of

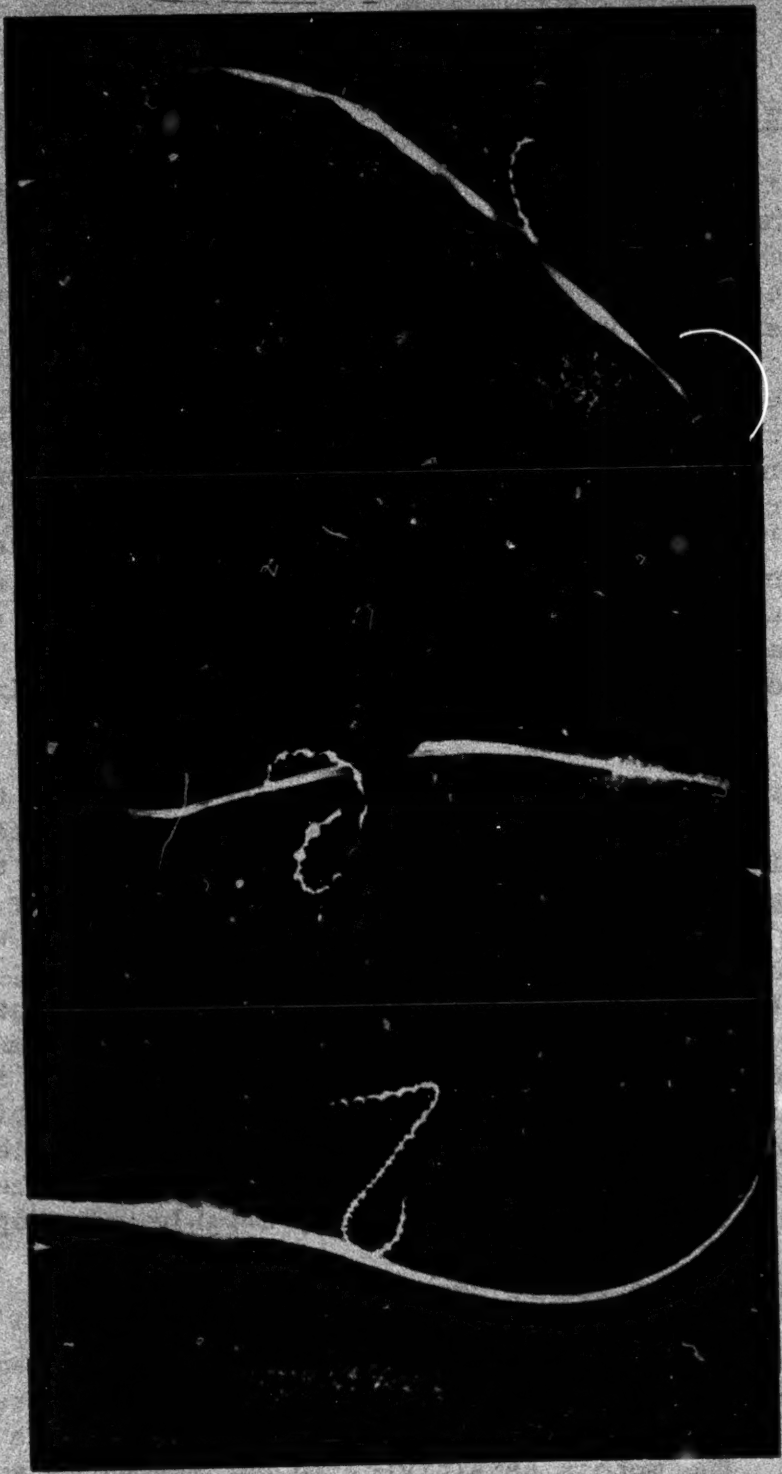


Figure 3. Streak Pictures of Bat-Moth Encounters. For these pictures, free-flying moths were attracted to the area with the use of ultraviolet lights. When approaching bats were detected, the lens of the camera was opened and a Sylvania Sun-Gun was activated. The pictures were made with the collaboration of A.E. Treat, using the technique suggested by K.D. Roeder. The middle and lower portions of the Figure will appear in a publication by Roeder.[28] Due to the absence of a time marker, the time relations cannot be specified accurately. The top third of the figure illustrates the capture of a moth immediately after the moth's initiation of a dive or diving spiral. The middle third shows a remarkably precise

Figure 3 (continued).
predictive evaluation of the moth's horizontal spiral. The bottom third of the Figure demonstrates successful evasion by the moth with the use of a sudden secondary loop-back. Apparently expecting the downward dive to be sustained, the bat continued its high speed course without deflection when the loop-back occurred.

little directional evaluation. Whether or not a moth can judge the bat's phase of interception is not yet established; but moths often initiate evasive tactics, or make sudden changes in them, roughly as the bat begins its final phase of attack (see Figure 3). Likewise, whether or not a moth can judge its distance to the ground or to nearby shrubbery is at present unknown. One might be tempted to guess that by use of the time intervals between a bat's direct signal and the corresponding echoes from the ground or other objects, a moth might make some estimate of the location of such objects. Evaluation of this possibility, however, awaits test.

What does a moth do upon the detection of a bat? What a moth does, upon detecting a bat is not easy to state concisely. The maneuvers executed by moths seem both diverse in their nature and erratic in their timing. Roeder states, "The difficulty experienced in classifying these nondirectional evasive movements is perfectly significant in the biological situation, since it may be expected to tax the prediction powers of the predatory bats as well as those of the experimenter."[27, p. 57] Some of the more typical responses of evading moths are shown in Figures 3 and 4. Others are presented by Roeder and Treat.[30, p. 145] Sudden dives, often with sharp loops back, occur frequently with a bat's close pursuit. Variously oriented spirals of constant or varying radius are also seen in the presence of bats. But loops, sudden shifts of direction, spurts of speed, and abrupt cessations of flight--often with unpredictable-seeming time relations--occur in so many combinations that the bat's prediction problem, certainly as we see it, must often be extremely difficult.

Yet if long evolutionary development has shaped the evaluating mechanisms of the bat, the bat's analytical system may incorporate some very effective probability indicators that permit it to judge, better than we as outside observers, the zones where an evading moth is likely to go. Certain observations by Roeder and by Treat are suggestive; namely, that the reaction times of moths (particularly with reference to these so-called "nondirectional" maneuvers) ranged from one-fifth of a second to one second. In this amount of time, the bat accomplishes a large proportion of its interception. If the moth's maneuvers are triggered by particular changes in the bat's signals, then the bat has a significant interval during which the moth is likely to continue the evasive tactics already initiated.

That evasion works, however, has been quantitatively demonstrated by the compilations of Treat. Using Treat's figures, Roeder and Treat[32] demonstrated an enormous advantage in terms of likelihood of escape for moths which evaded, as against those which did not, approximately half of the observed attempts on nonreacting moths resulted in catches, whereas only about 1/14 or 7 percent of the observed attempts on reacting moths were successful. Little systematic observation of evading moths has been made with bats other than _Lasiurus_ and _Myotis_; moreover the observed results--as clearly pointed out by the authors--cannot be taken as the total picture of evasive advantage. In the laboratory, a few _Galeria_ moths were flown in the presence of _Myotis lucifugus_ and of _Plecotus townsendii_. The moths would quickly land, or not fly at all, when _Myotis_ were active. They were commonly quite willing to fly, however, when _Plecotus_ were flying. Indeed, _Plecotus_ bats sometimes seemed able to come up behind the moths without producing evasive tactics, or producing them only at the very last instant. Possibly the very low signal level of _Plecotus_, or the low level combined with a lower

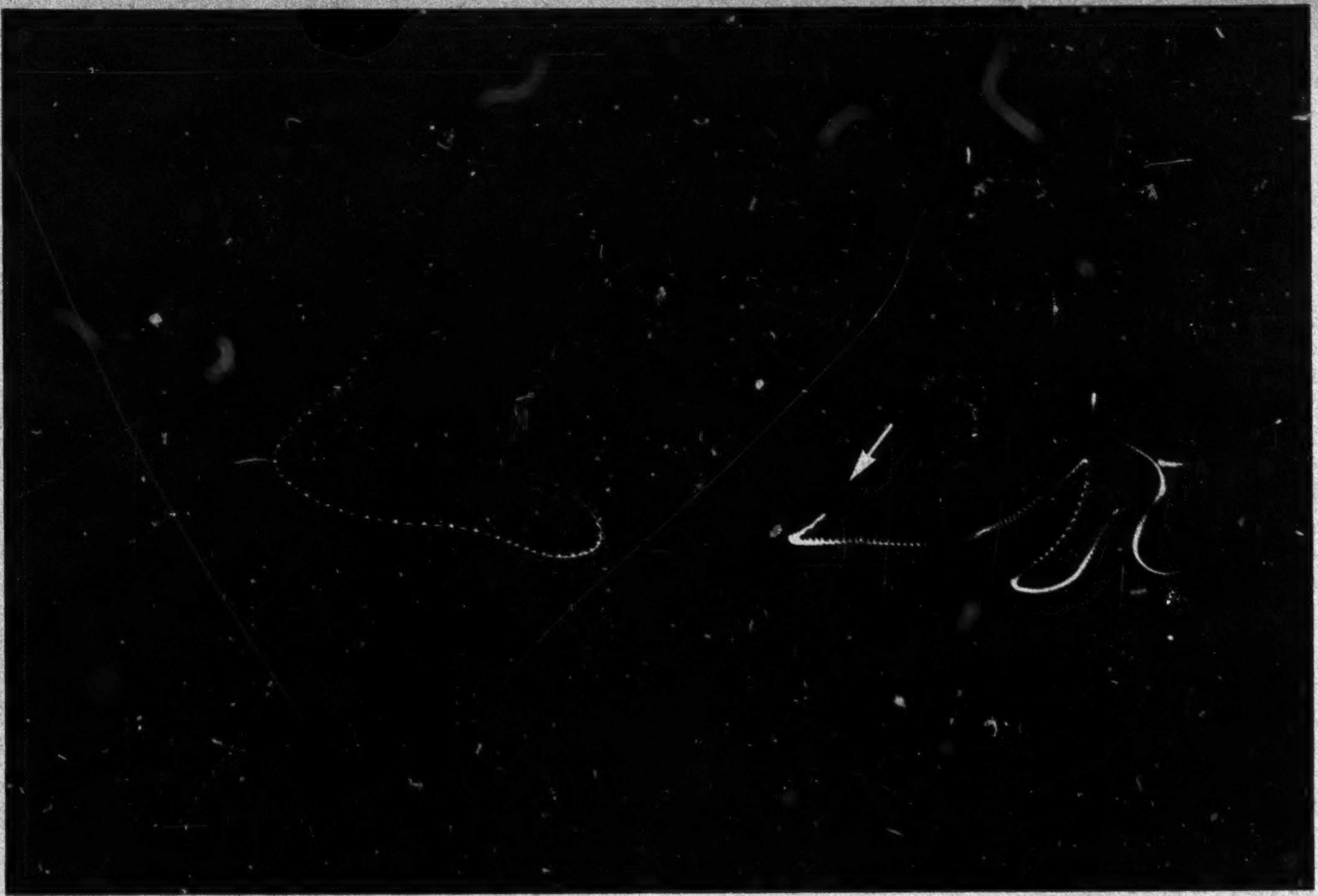


Figure 4. Continuing Evasive Tactics by Moths. The tracks of two moths are shown in this streak picture (made in conjunction with A.E. Treat). Arrow points to the sudden initiation of looping evasive tactics by one of the moths. Note the apparent randomness of the direction but not of radius. Other pictures have shown sudden variations in turn radius and in other attributes of the evasive pattern.

frequency range[12] causes the signals to fall below threshold for the excitation of evasive tactics.* At the other extreme, the high flight speed of the red bat may be partly designed to get it to the intercept point before the moth has a chance to change its tactics significantly. Here the predictive powers of the bat, and its techniques of capture, tend to outwit the evasive skills of the moth. At the present time, observations are few and speculations many. For the most part, the true story remains to be discovered.

The Ultrasonic Signals of Moths

The escape techniques of moths are not limited to evasive maneuvers. Important among the moth's countertactics is the production of ultrasonic pulses, presumably in response to the orientation sounds of bats. The sound making mechanism of two Arctiid moths have recently been described by Blest, Collett, and Pye.[2] Moreover, Roeder (unpublished) found that the production of pulses by Halysidota moths could sometimes be set off or terminated by bat-type pulses, the effects often being related to pulse intensities. Though present evidence is extremely limited, it suggests that definite relations may exist between the sets of signals on the two sides.

---

*Or it could be that the moth interprets the low signal level as if the bat were at a greater distance; and consequently takes directional action (e.g., turning away from the bat), but does not initiate violent evasive maneuvers.

What action do the moths' pulses have upon the pursuit actions of bats? One set of tests, carried out by A.E. Treat with red bats and Halysidota moths at Tyringham, Massachusetts, produced some striking, if limited, evidence. Various kinds of moths were being tossed by Treat into the approach paths of red bats, Lasiurus borealis. In almost all cases, the bats either captured the moths or made serious attempts at pursuit. However, with a particular kind of moth, Halysidota, one set of results was strikingly different. Out of about a dozen tosses of Halysidota the bats appeared to veer away in all but one instance. In subsequent tests, Treat found the results to be less striking (personal communication); but the observed tests left no reasonable doubt that under certain conditions Halysidota moths were selectively avoided by the red bat. Whether the moths were actually emitting sounds at the time of the test was not established; hence it is possible to reason that features other than sound emission may have caused evasion by the bats.

Unfortunately, at the time Halysidota moths were available for tests in the laboratory, red bats were not, and vice versa. Tests were therefore carried out with the little brown bat, Myotis lucifugus. Here the results were rather variable, Halysidota moths sometimes being caught with probabilities similar to those of the other moths tested at other times being largely avoided. However, the tiger moth, Apantesis virgo (and perhaps one or two other Apantesis moths), appeared to produce invariable avoidance during a very limited set of tests. In the course of a series of tests covering a total of 61 tosses of various targets, including 14 of active tiger moths, only the tiger moth was always avoided. Figure 5 illustrates the results of all tests which included tosses of tiger moths. As shown in this figure, when moths other than Halysidota or tiger moths were tossed, 16 out of 20 were caught or hit (and all but one apparently attempted), yet the 14 tosses of active tiger moths gave rise to no attempts. Results with Halysidota moths were in between. Lack of suitable instrumentation prevented discovery at this initial stage of whether the moths under test were actually emitting clicks or pulses. A very limited supply of moths also prevented any really adequate collection of data.

Certain tests, however, were made on the sound emission of the moths used, including several Halysidota and several tiger moths.* These tests suggested that the production of clicks by Halysidota moths was somewhat less reliable than the production of clicks by tiger moths. In all cases where active tiger moths were tossed in front of the microphone, clicks were noted. In the case of one moth and one bat, an effort was made to see if the occurrence of clicks in the moth was related to the avoiding action of the bat. In this one case, a tiger moth was projected upward four times and each time was avoided by the Myotis bat under test (Figure 6); it also always produced clicks when projected close to a microphone between tosses to the bat. In the course of a long series of tests, significant clicks finally disappeared. At this point, the moth was again projected by catapult to the same bat. The bat immediately made an attempt, and caught successfully on the second try (Figure 7). Since the moth was also less active at this juncture, the catch could have been due to the simpler nature of the interception. During the test, however, this bat was making serious pursuits of other moths, regardless of their degree of activity, suggesting that sound emission rather than flight activity was the key factor. While no definite conclusion can be drawn from this single instance, there is again the suggestion that the bat's pursuit may have been significantly

---

*Sound emission was tested chiefly under the following four conditions: 1) holding the moth by the wings (thus eliminating possible sound production from the wing action); 2) rolling the moth slowly around on the inside of a jar; 3) dropping the moth in front of a microphone; and 4) projecting the moth upward in front of a microphone by use of the same gun that was used for projecting targets to bats.

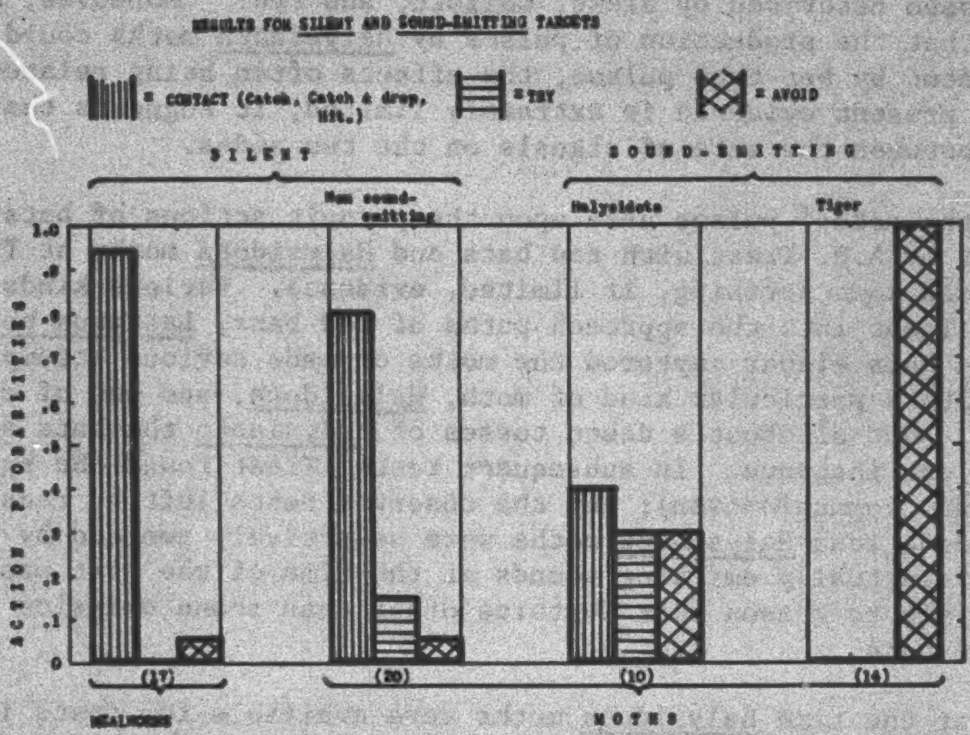


Figure 5. Interception Results (with *Myotis lucifugus*) for Silent Versus Sound Emitting Targets. The two silent target groups consisted of a) mealworms and b) silent moths (i.e., those giving no evidence of significant sound production when manipulated within about an inch of the microphone). The two sound emitting groups comprised a) *Halysidota tessellaris* and b) one or two closely related species of *Apantesis*, or tiger moths, including *Apantesis virgo*. Thirty-five of the 37 tosses of silent targets resulted in definite attempts at capture, whereas only 6 of the 24 tosses of sound emitting targets resulted in such attempts. Actually, the *Halysidota* moths were not tested for sound emission in the experimental situation. No active tiger moths (out of 14 tosses) were attempted. One tiger moth was projected about a dozen times in front of a microphone and in each case produced clicks.

influenced by the ultrasonic pulses of the moth. Taken together, the several instances seem to warrant the guess that certain moths may sometimes escape capture by emitting ultrasonic pulses when pursued.

Accepting for the moment the speculation that moths emit ultrasonic pulses to escape capture by bats, we must next inquire as to how the moth-emitted pulses act upon the bat. Do they warn the bat of some obnoxious or dangerous attribute? Are they pseudowarning signals mimicking, perhaps, the signals of some rare or remote target with dangerous attributes, or might they act chiefly to jam the bat or to produce clutter which the bat could not easily resolve? They might, for example, be triggered singly or in groups so as to give phantom echoes, or echoes producing false impressions of position, path, or velocity. At this early stage we do not know. This much, however, we can say: *Halysidota* moths represent one of several species possessing fine spurs and claws which project from long and spindly legs. These features enable such moths to cling obnoxiously to a bat's fur. *Myotis* bats, for the most part, prevent such fur-clinging by their techniques of catch (Figure 8). But occasionally their procedure fails; and under such conditions they have been observed to struggle for a significant portion of minute, losing altitude and expending obviously unusual effort. Red bats commonly use a

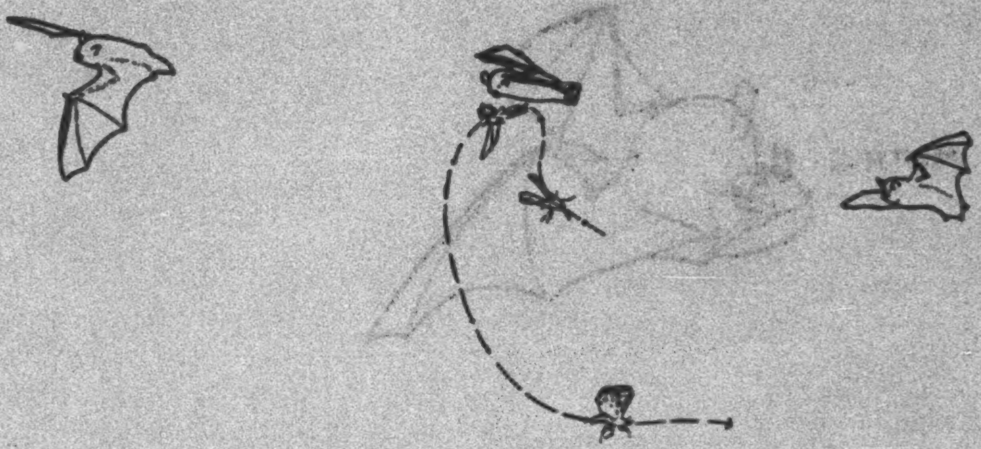


Figure 6. Reactions of *Myotis lucifugus* to Tiger Moths: Avoidance of Active Tiger Moths. Note the curling back of the bats ears and the slight closure of the mouth, often noted when bats relinquish pursuit.

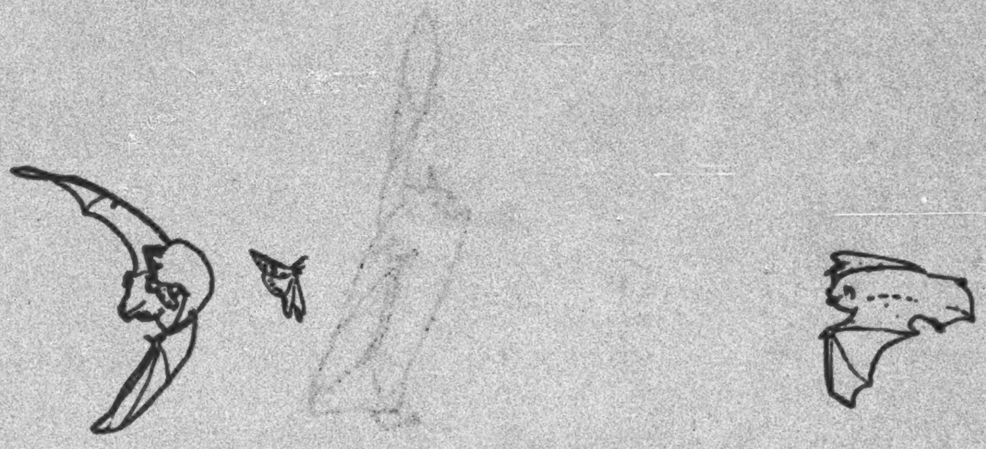


Figure 7. Reactions of *Myotis lucifugus* to Tiger Moths: Catch of Inactive Tiger Moth. Tests had indicated absence of significant clicks prior to this toss.

different procedure for catching, and they often hold their targets in a fur-lined pouch formed by the interfemoral membrane and the hind legs (Figure 9). It seems likely that the *Halysidota* moths would thus have a much better chance to grasp the fur of a red bat than of a *Myotis* bat; and that they might indeed constitute a menace which the red bat, when warned, would assiduously seek to avoid.

The riddle of the tiger moth remains with few clues pointing to a solution. It is true that some moths of the tiger group have proved unpalatable to some animals, but the tiger moths under test were eagerly devoured by *Myotis* bats. The case for pure jamming, in the sense that the bat's hearing of echoes from the moth is prevented by the moth's pulses, seems unlikely. Existing evidence suggests that jamming is difficult, even by wide band noise within the bat's frequency range, once a bat has locked onto its target. Evaluation of obstacles in the presence of very high noise levels has also been amply demonstrated.[11, 12] The possibility of phantom or misleading pulse configurations remains open. Experiments have shown that many *Myotis* bats avoid clusters of targets, and targets that are too suddenly displaced. But other *Myotis* bats, and certainly the one red bat thus far tested, are extraordinarily proficient at selecting one out of many moving targets in a cluster (Figures 10, 11, and 12). One thing, however, does seem to interfere with the pursuit procedure of most bats; namely the existence of one large target and one or more nearby smaller targets. Though highly unlikely, it is conceivable

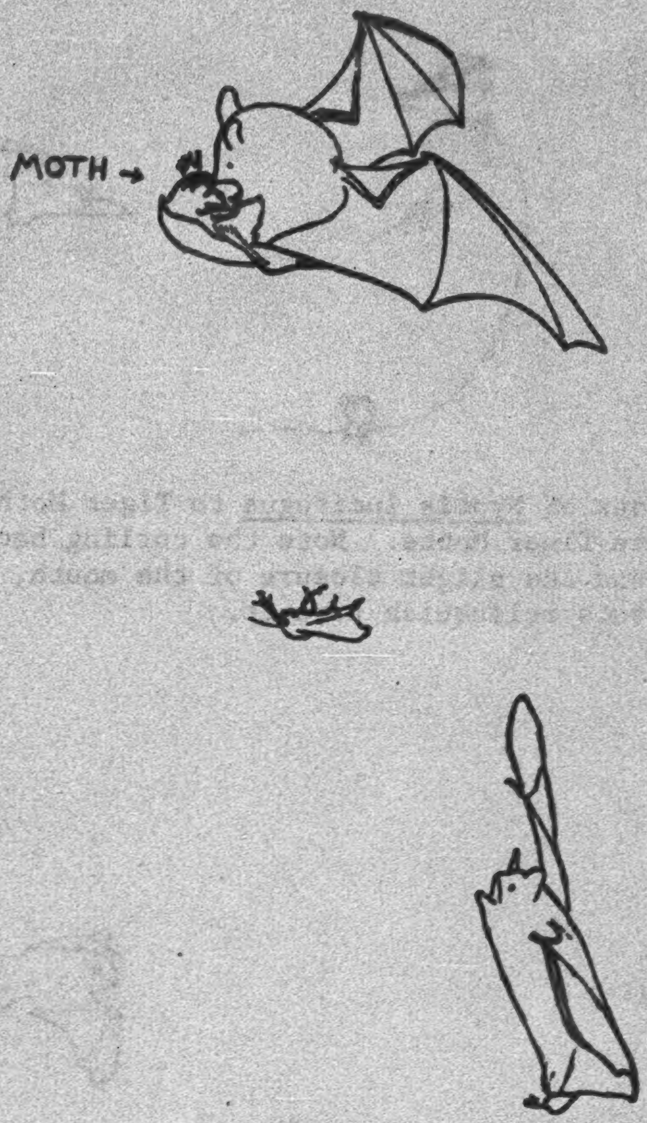
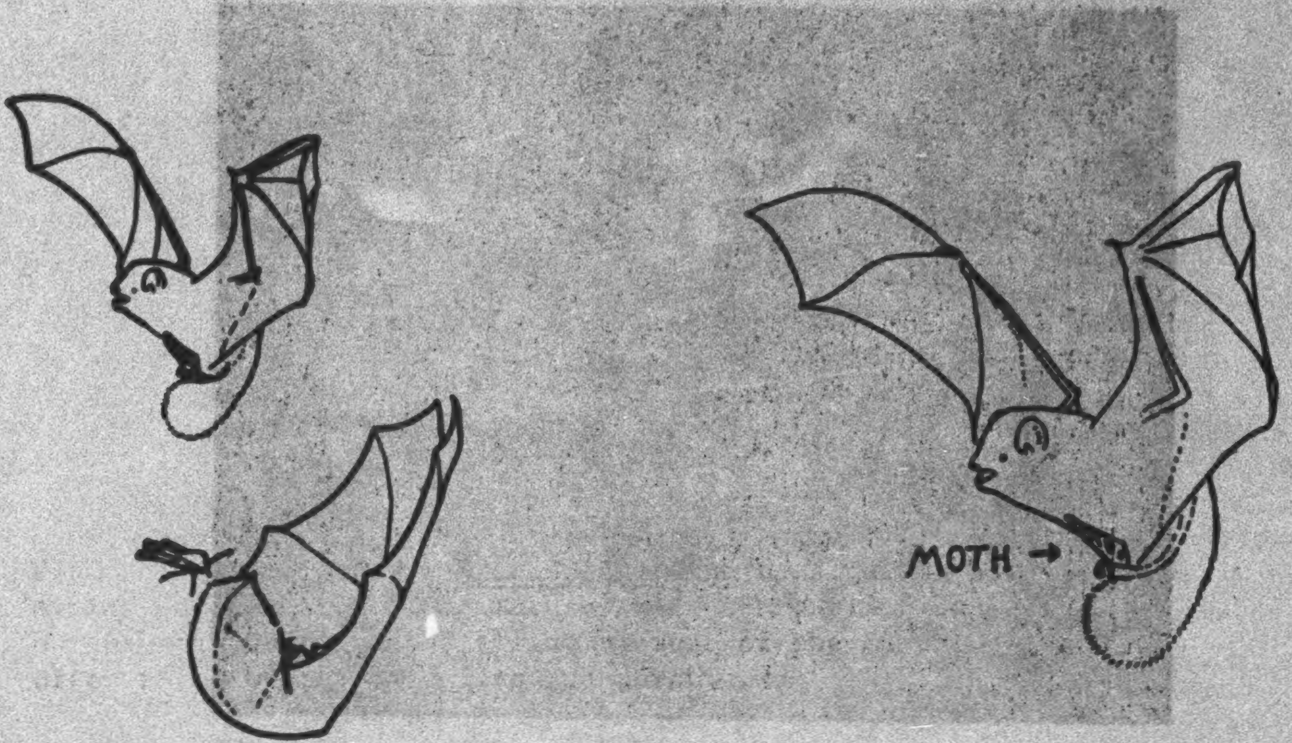


Figure 8. Catch of Halysidota by Myotis lucifugus. The moth is normally quickly seized, as here, so that the legs point outward and cannot grasp the bat's fur. Occasionally such moths succeed in grasping the bat's fur and cause obvious distress.

that the moth's pulses could create some such impression. At this stage, however, all such ideas are purely speculative and serve only to indicate some of the directions the search may take.

The final aspect of the moth's system deserving mention is the mechanism of sound production. The sound generating mechanism of Halysidota is illustrated in Figure 13. Studied intensively by Blest, Collette, and Pye[2] the mechanism was found to operate much in the manner of an array of toy clickers or crickets. By pounding dents into a strip of spring steel and then bending the strip so that the dents popped out and releasing it so the dents popped in, these investigators generated sounds which were virtually indistinguishable from the pulses of the moths when slowed down with the use of a variable-speed tape recorder. A somewhat similar tymbal organ was noted by Treat (unpublished) on the episternum of the tiger moth Apantesis virgo. Here, however, no row of dents or creases was evident, in keeping with the observation that the pulses of the tiger moth tended to be single or paired rather than grouped. A comparison of the pulses and pulse sequences of Halysidota and tiger moths is given in Figures 14 and 15. The story, however, appears to be more complex than the simple tymbal organ suggests;



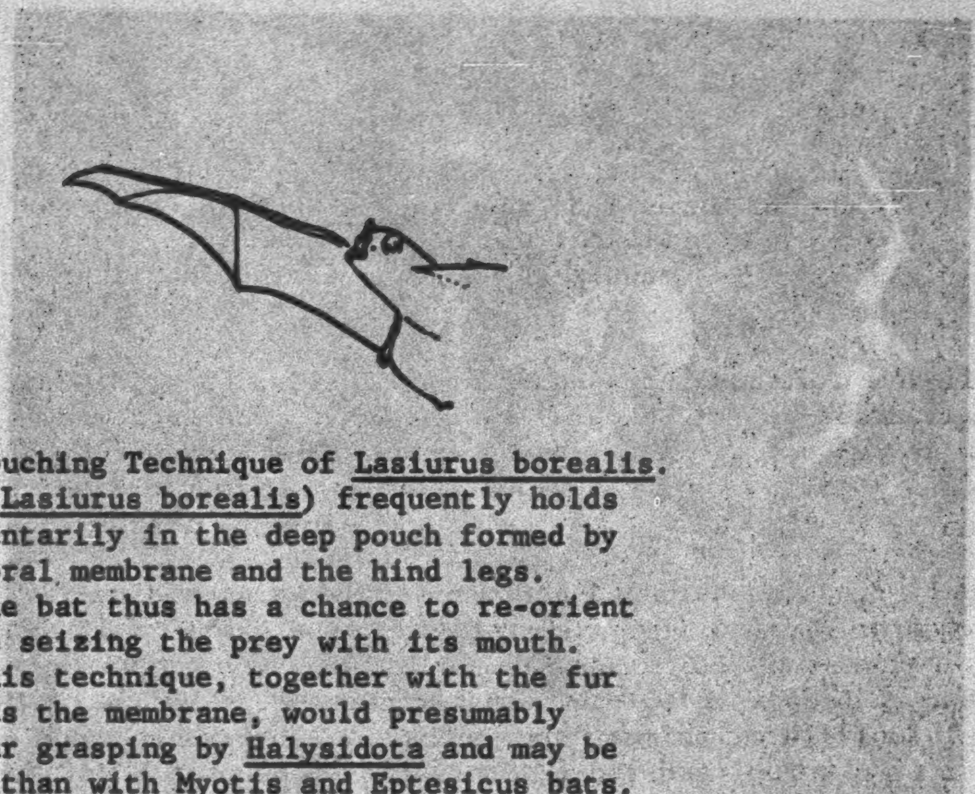


Figure 9. Pouching Technique of Lasiurus borealis. The red bat (Lasiurus borealis) frequently holds its prey momentarily in the deep pouch formed by the interfemoral membrane and the hind legs. Apparently the bat thus has a chance to re-orient itself before seizing the prey with its mouth. The use of this technique, together with the fur that surrounds the membrane, would presumably facilitate fur grasping by Halysidota and may be more serious than with Myotis and Eptesicus bats. (Note wing of moth projecting out of pouch.)

for abbreviated pulses were readily detectable even after complete longitudinal cutting of the outer tymbal surfaces. It is thus possible that two or more sound producing mechanisms or modes of operation contribute to the click complex of these moths and give rise to a versatility of sound emission that produces more than one effect upon the auditory reception of bats.

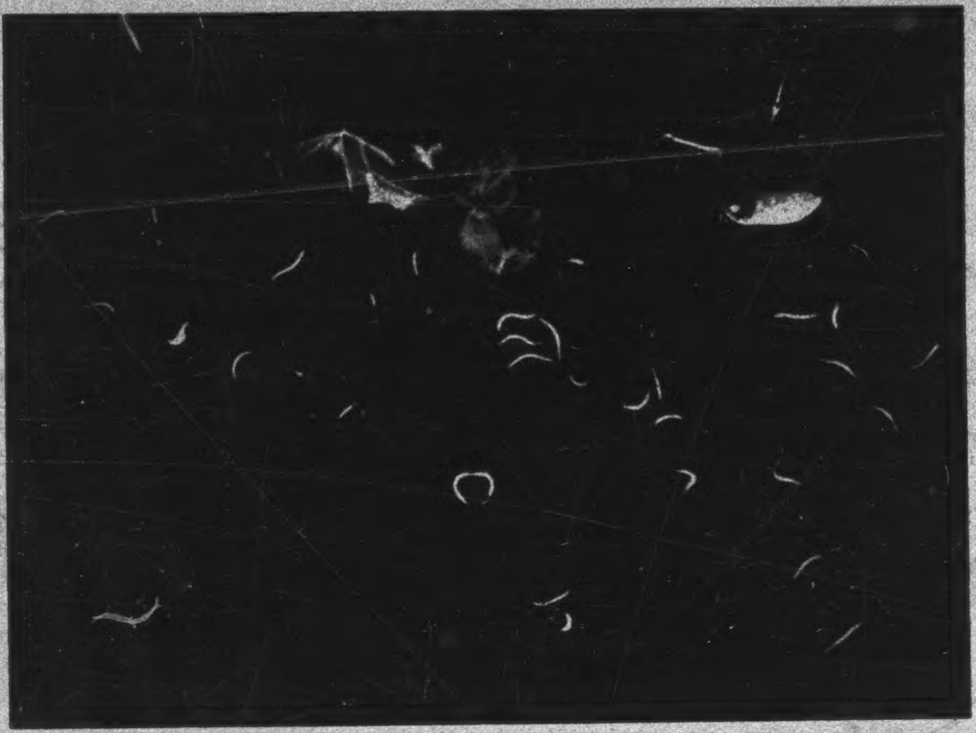


Figure 10. Selection of One Target Out of a Cluster: Catch of One Out of Eight Mealworms by Myotis lucifugus. Two flashes occurred while the bat was out of the field; the lowest group of eight mealworms correspond to the second flash. (In the upper two overlapping images, the bat is reaching into its tail membrane to seize the captured prey.)

Figure 11. Selection of One Target Out of Cluster: Catch of One Out of Fifteen Mealworms by Lasiurus borealis. At the last image (left), the mealworm is in the bat's pouch. On the next circuit by the bat, 25 mealworms were tossed and the bat turned away.

Figure 12. Selection and Catch of Mealworm from Three Spheres by Lasiurus borealis. Two of the spheres approximated the average reflectance of a mealworm; the other was smaller. Placed above the path of the bat is the pulse sequence for this catch. Connecting lines show the approximate relation of approach path to emitted pulses. The reason for the terminal change in angle of these lines (end of sequence being indicated by heavier broken line) is the sudden slowing down by the bat just before the catch. In Figures 33, 34, 35, and 36, the relations of signal to action are given in more detail.

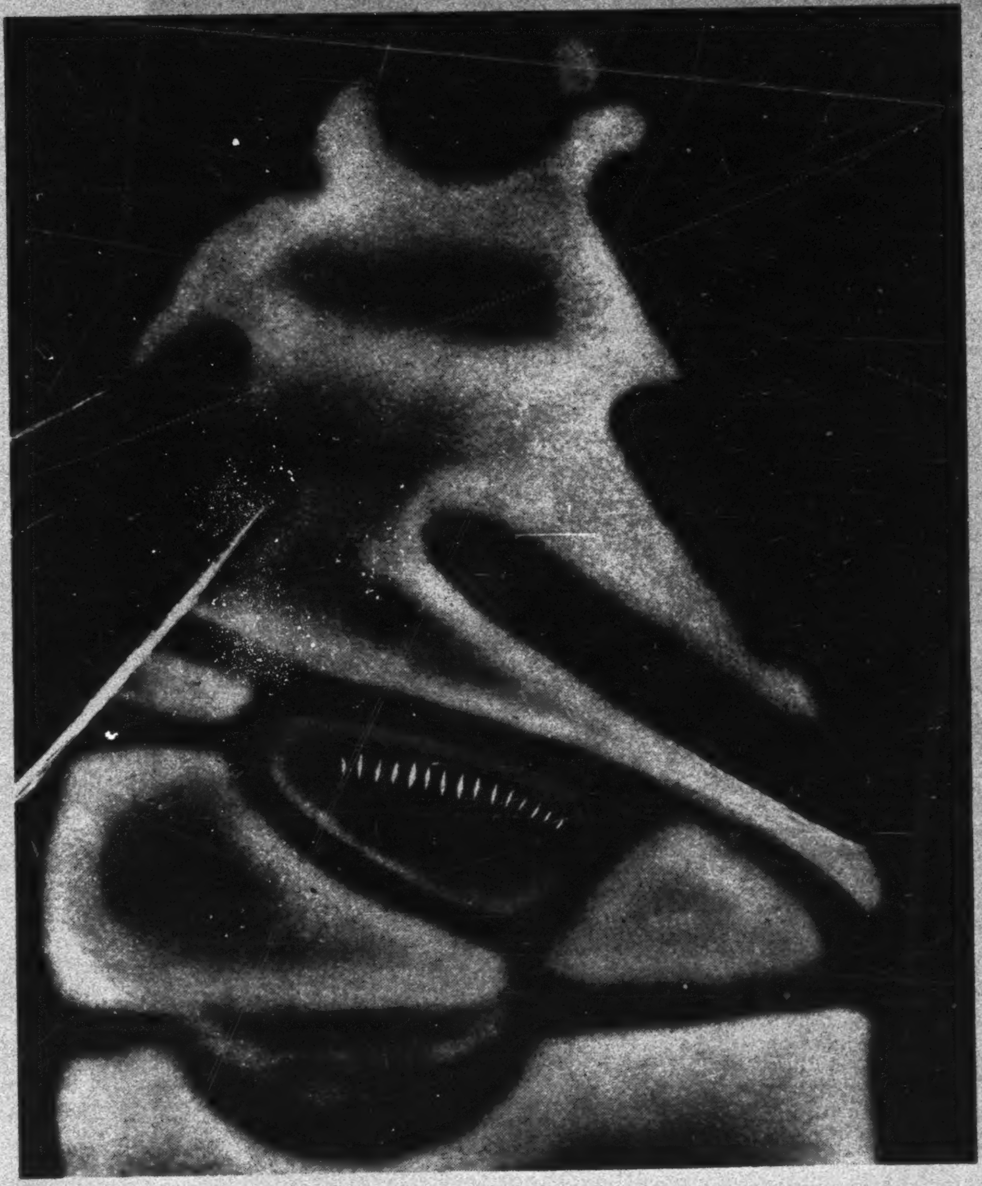


Figure 13. Tymbal Organ of Halysidota tessellaris. Row of microtymbals shows as a line of creases or grooves on the surface of the hard shelled and hollow episternal sclerite. When the row is bent by muscular action the grooves pop out, producing a set of clicks. Another set of clicks occurs as the grooves pop in with relaxation of the muscle. Details are given in Reference 2. Curved area protruding toward abdomen is the tympanic organ. Dark areas along ventral side are moth's legs; wing bases are indicated on dorsal side. (Traced semi-schematically from a photograph of one of the moths used in the tests.)

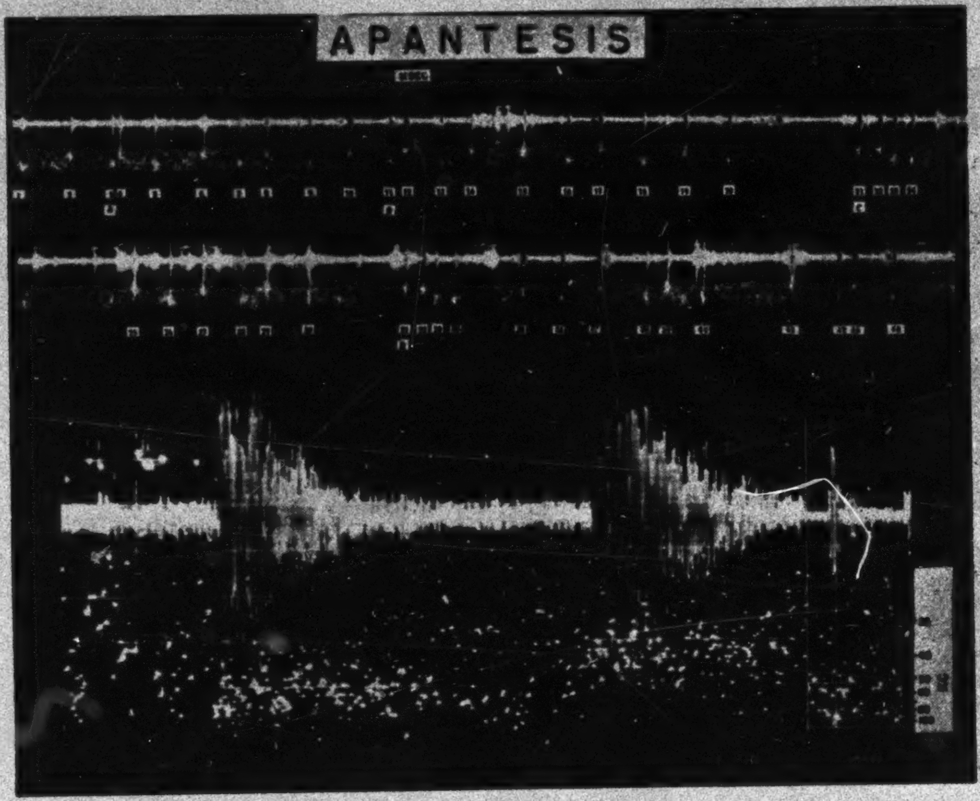


Figure 14. Pulse Sequences and Pulse Groupings of *Apantesis* and *Halysidota* Moths: *Apantesis* (Tiger Moth) Pulses. The upper pair of traces shows a typical sequence of pulses recorded from a moth that is being handled within an inch or two of the microphone. Individual pulses are numbered, and four groups of interest are designated by letters. The enlarged tracing just below shows a pair of pulses similar to the pair labelled *A*. Along the side of this tracing is a frequency calibration which refers to the output of a zero-crossing meter. Intervals between crossings appear as dots. In the present pair of pulses the crossings correspond to a clustering of frequency components around 45 to 70 kc for the first pulse, and roughly 35 to 50 kc for the second. Pulse durations are roughly 3 milliseconds. Details of the frequency structure cannot readily be seen in the upper tracings. However, the different frequency clusterings are readily observable. Thus, group *B* (Numbers 11 through 14) show pulses alternating between higher and lower frequencies, but the second pair (13 and 14) shows a wider frequency scatter than the first pair (11 and 12). In groups *C* and *D* the ordering of the frequency groups is different: two lower frequency pulses are followed by two higher frequency pulses in each case. Presumably the two frequency ranges correspond to the tension and relaxation modes of sound generation; the smaller and larger frequency scatters are associated with left and right positions. However, this moth has the capacity to control various features of its pulses, most notably pulse length. By cutting down the resonance of the terminal portion of the pulse, apparently, the length can be reduced to one-third millisecond or less. Such abbreviated pulses are also recorded when the tymbal organs are cut open (see insert at right). The moth may indeed have some control over frequency and frequency scatter of the individual pulses, as also of their duration.

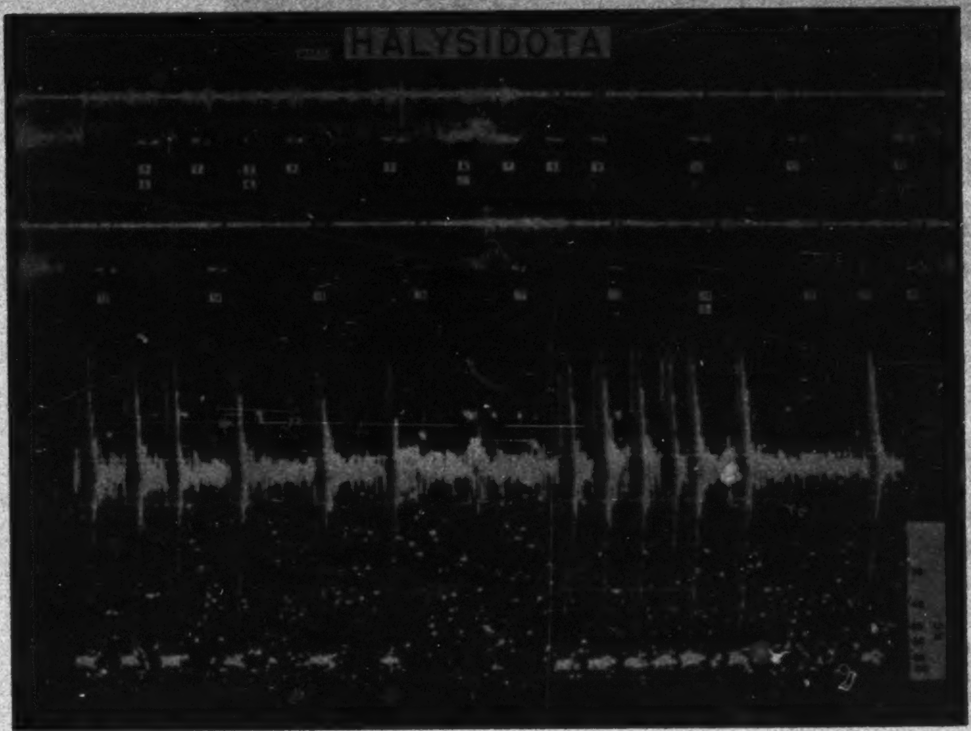


Figure 15. Pulse Sequences and Pulse Groupings of *Apantesis* and *Halysidota* Moths: *Halysidota* Pulses. The conditions and arrangements are the same as for the previous Figure, with the exception of the numbering. Here, each number specifies a total tension-relaxation group of pulses. The enlarged tracing is of the first pair of pulse groups (A), where the initial phase of operation of the sound mechanism produced six pulses and the ensuing phase produced six still more closely spaced pulses. An isolated pulse occurred shortly afterward, and other more or less isolated pulses occur in the regions labelled B and C. The longest group in the present series, labelled D, contains eleven pulses in each phase. Much variation in pulse numbers and spacings occurs through the record. In the enlarged tracing it is evident that the frequency components are concentrated close to 80 kc, with little evidence in this record of a lower fundamental (as noted in Reference 2). There is also little of the frequency scatter seen in the pulses of *Apantesis*. Indeed, the slowed down pulses of *Halysidota* sound much like the to-and-fro tinkling of a slightly rusty bicycle bell, while those of *Apantesis* sound very similar to corks being pulled out of a couple of bottles in sequence. Individual pulses of *Halysidota* are mostly of one-third to one-half millisecond in duration, while the total two-phase grouping typically runs from about 8 msec (in Number 9) to about 16 msec (in Number 19).

The properties of the targets and the implications for their bat predators can perhaps be summarized as follows. The flying targets caught by bats exhibit a great diversity of size, probably from about one-fifth of a milligram to over 200 milligrams--a range of 1000 times or more. The evidence suggests that although most bats may not select the very small insects habitually, they probably can when necessary. The signals and techniques of bats appear, for the most part, to provide for such contingencies. Yet, as mentioned earlier, the signals and techniques of different bats may be adapted primarily for the capture of particular groups of insects. Some bats, for example, seem to specialize in catching very small insects in rapid sequence, whereas, others seem to specialize in making less frequent captures of much larger and more difficult targets. Some larger targets, notably certain night flying moths, have evolved special methods of escape. Many possess sensitive hearing and, when pursued, initiate violent evasive maneuvers of an apparently unpredictable nature. Others evidently send out ultrasonic pulses themselves in response to the pulses emitted by the bat, these pulses serving in several different ways to produce cessation of the bat's pursuit. With this background, the rationale behind the bat's methods may be more evident, and we can examine in a little more detail the actual procedures used by the bats and the relation of these procedures to the bat's signals and to the action of the targets.

ANALYSIS OF OBSERVED DATA

The first part of this paper has been devoted to a survey of some of the main features of insectivorous bats, their echolocation signals, and some special aspects of their survival problems, with particular reference to the interception of the insect targets on which they lived. The second part will illustrate a few specific results of the preliminary observations on how they catch, how accurate their aim is, and how they deal with special problems mentioned in the sections above. The questions we are trying to answer are roughly these:

(1) How do bats catch? How rapidly do they catch? How accurate is their aim and how reliable their technique?

(2) What can a bat judge about its target in advance of capture? For example, can it identify the target and predict what the target's action is likely to be?

(3) How are the bat's signals related to the interception problem they are solving?

In the past, popular belief has been quick to overlook the more obvious requirements of a bat's interception problems. The erratic-seeming escapades of bats against the sky have commonly been considered as idle play or unexplained perversity. To catch the insects on which it lived, a bat was presumed to fly straight ahead with its mouth open, scooping in its prey from insect swarms much as a whale scoops plankton from the sea, or possibly by homing in on the steady hum of a straight flying mosquito or beetle. The absurdity of the idea that bats could feed by simply flying straight ahead with their mouths open has been amply illustrated by the calculations of Griffin and others.[5,6,7,8,14,40] A bat could not obtain even a thousandth of its required food in such a way. Homing in by passive listening to the insect's hum, while it may sometimes be used, could not account for the rapid and skillful interceptions that have been observed on essentially silent targets.

Far from being simply the aimless and erratic dartings of a playful creature, virtually every plunge or zoom may end in a precise interception and catch, initiated at distances that may vary from as much as 1 to 20 feet or more. Successive catches, moreover, may be achieved in remarkably short intervals of time. It is clear that a bat's signal system not only permits the bat to perform interceptions on difficult targets with extraordinary speed and precision, but that it also enables a bat to avoid serious mishap and to survive in a complex environment for periods as long, perhaps, as 25 years. In the following discussion, we look at some of the details which go into the bat's extraordinary performances.

HOW DO BATS CATCH?

Preliminary Observations

Early in the course of the present studies, preliminary observations of Myotis lucifugus bats catching mosquitoes and fruit flies suggested that the bats caught by one or two methods. In one case, they appeared to aim at a straight flying target, the target apparently entering the mouth directly. In the second case, the target appeared to be slightly below the bat or slightly off to one side. Here the bat seemed to scoop it up with the tail membrane, balling up tightly and reaching down with its mouth to pick out the captured insect. Photographs soon revealed, however, that the tail membrane was always brought up over the mouth at the time of capture, but that in some cases the bat's mouth did indeed continue directly for the insect. (Recent high speed films showing details of catches by Rhinolophus ferrum-equinum indicate variable use of the tail membrane. Extensive use is made of one or both wings, with direct transfer from wing to mouth apparently sometimes occurring.) Often the tail membrane was brought up only for a dozen or so milliseconds, apparently either to help knock the insect into the mouth or to make certain the insect did not escape (as, for example, in case of a small error of aim or of a rapid last-instant maneuver by the target). Additional photographs showed that when a fruit fly was off to one side it was sometimes first captured in the membrane of one of the wings. The most striking feature of these pictures, however, was the very precise aim of the head and ears (Figures 17, 22, 23, and 25). Almost invariably the aim was so precise that it was impossible to detect any error, at least from the pictures. It was thus clear that the bat knew exactly where the fruit fly was and could keep its head directed toward it accurately at all times. Also obvious, however, was the fact that the bat could not always get its body to the correct spot and that in such cases it appeared to reach out a wing for initial contact. Such catches did not necessarily represent an error of aim. Catches of fruit flies are shown in Figures 16, 17, 18, and 19.

Techniques of Catch Used by Myotis lucifugus

To photograph the details of catches in the laboratory, a somewhat artificial situation was used. A solenoid-driven "gun" was developed (by D.A. Cahlander). This gun projected the targets upward to a prescribed zone so that the interceptions could be accurately photographed. The initial target was the standard laboratory food of bats, namely the mealworm (roughly 2-1/2 by 20 mm in size). Although such targets moved in a more or less vertical ballistic trajectory, very different from the trajectory of fruit flies, the bats appeared to use very much the same techniques of catch.[40] Certain variations and additions, however, were noted. The techniques observed can perhaps most conveniently be divided into three somewhat overlapping categories as follows.

Tail Membrane Catch (Figure 20) When the bat is able to make a reasonable evaluation of the trajectory of a ballistic target, and can readily direct its flight path to the intercept point, it characteristically attempts a tail membrane catch. Here the bat's aim is such that the target normally strikes close to the center of the membrane just as the membrane is snapped forward to form a scoop or pouch. Head and membrane are then brought together and the bat either grasps the target immediately (coming out again in as little as one-twentieth of a second) or spends up to several seconds adjusting the grasp of the target with its mouth.

Wing Scoop Catch (Figure 21) Very commonly, the bat finds it easier to reach out for the target with its wing. Apparently, however, the bat's reflex technique of seizure makes use of the tail membrane and, consequently, the target always appears to be shovelled into the pouch of this membrane before it is grasped in the mouth.

Wingtip Catches (Figures 22 and 23) Sometimes, particularly with a rapidly moving target, the bat is able to reach the target only with (or close to) the tip of its outstretched wing. When this contingency is expected, the bat often uses a rather ingenious

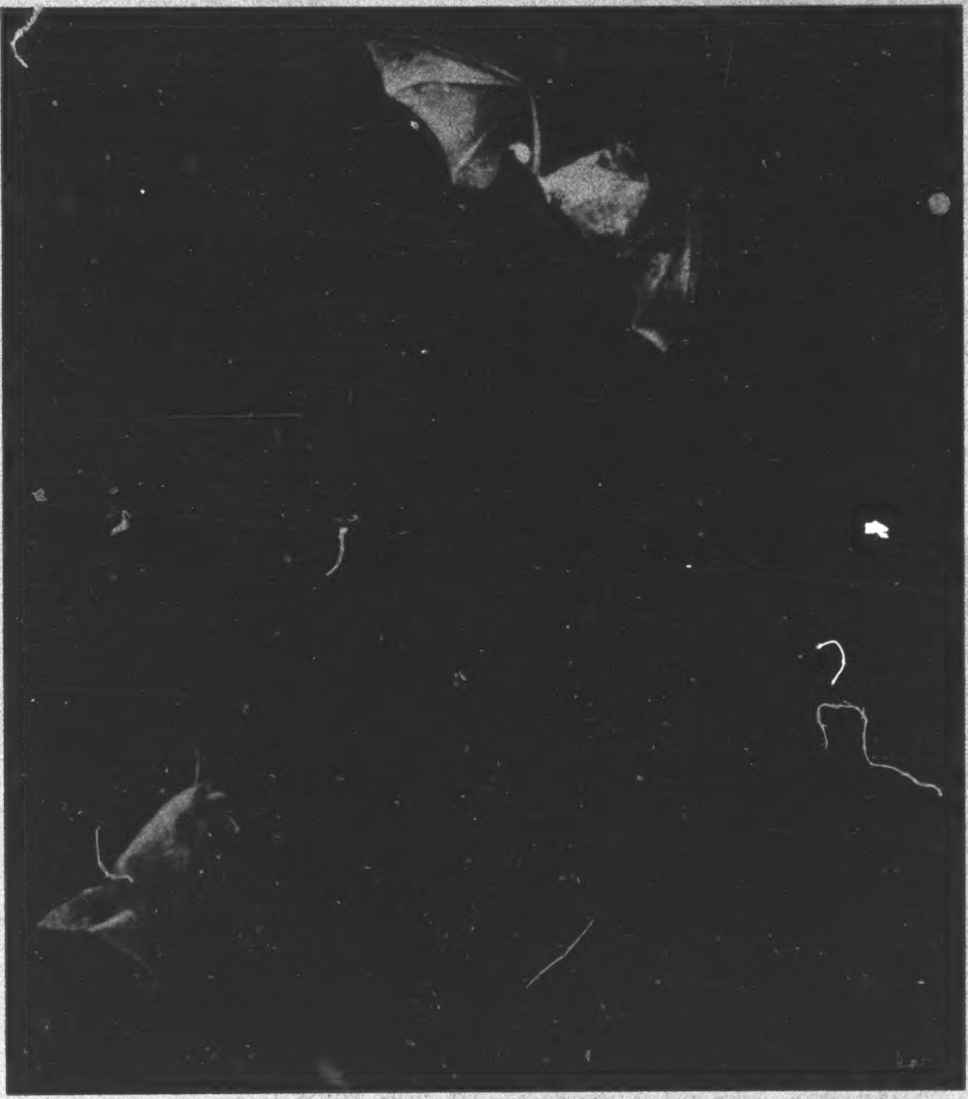


Figure 16. Accuracy of Aim by Myotis lucifugus. Though not of a fruit fly catch, this picture of the catch of a sphere indicates both the accuracy of the aim of the bat's head during the approach and the extremely precise centering of the target at the point of contact with the tail membrane. Note that the target is not followed with the head at the last instant, a situation commonly noted with ballistically-falling targets. Myotis bats have trouble evaluating rapid vertical velocities, and during early tests typically miss targets travelling rapidly upward or downward. Accuracy of aim for larger targets is normally established at a distance of three feet or more (see Figure 25). Some of the pictures indicate like accuracy at roughly two feet when the target is a fruit fly.

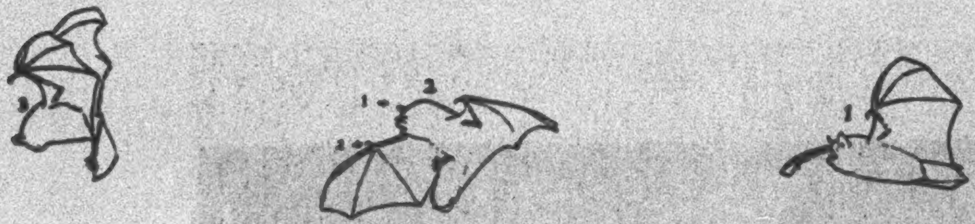


Figure 17. Typical Direct Catch of a Fruit Fly by Myotis lucifugus. The fly is headed downward and toward the bat's right, the bat evidently following its path with precision. At the center image (flash number 2) the bat's tail membrane is moving rapidly forward, and presumably scoops in the fly an instant later. The last flash shows the bat coming out of the catch with its mouth closed. About 1/20 second after this stage the bat is normally emitting pulses and is ready for another catch.

Figure 18. Possible Use of the Wing in the Capture of Fruit Flies. This Figure shows a forward reach somewhat similar to that of Figure 17, but in this case with sharply bent wing tip. The shadow of the fly shows as a dark spot on the wing. In the second image the bat is coming out of its catch.

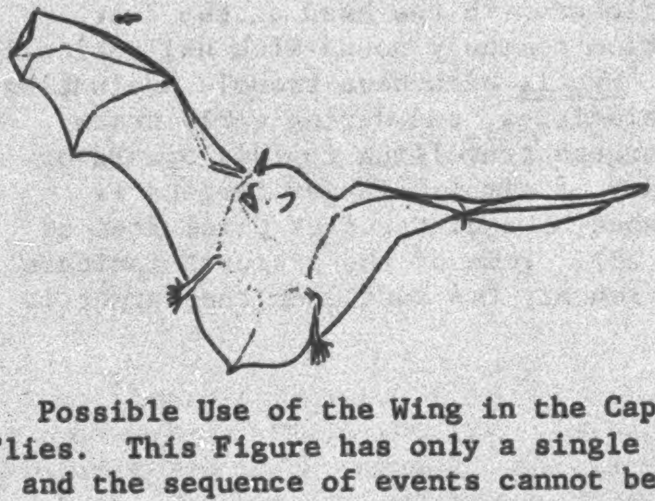


Figure 19. Possible Use of the Wing in the Capture of Fruit Flies. This Figure has only a single set of images, and the sequence of events cannot be judged. Late detection far to one side, however, may have produced the need for reaching with the tip of the wing.

Figure 20. Tail Membrane Catch of a Mealworm by Myotis lucifugus. Apparently the quickest and simplest method of catching is with a scooping action of the tail membrane. The bat's aim is commonly good enough so that the mouth is snapped directly to the point of contact of the target and membrane, the total in/out action sometimes occupying as little as 1/20 of a second. Inadequate localization or improper grasp of the target may, however, lead to several seconds of manipulation before the bat straightens out for normal flight. (Center image shows the mealworm in the tail pouch.)

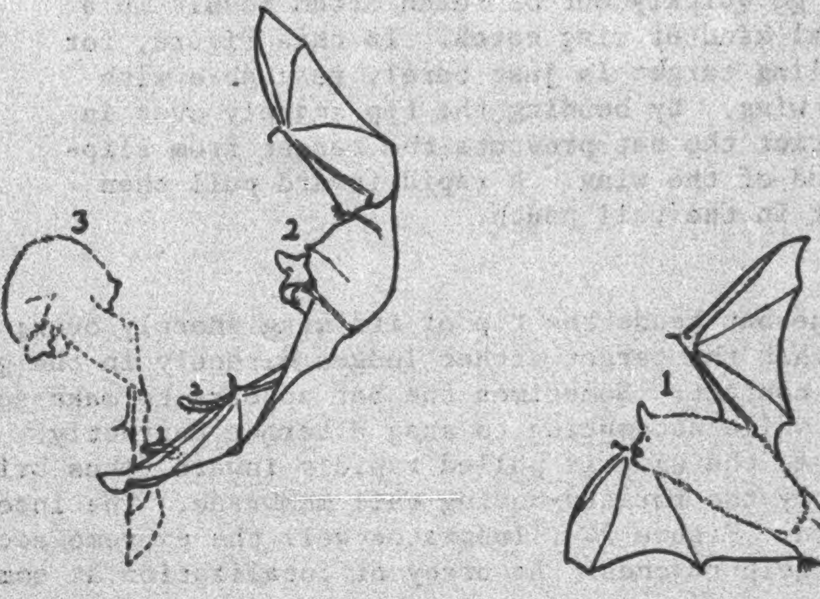


Figure 21. Wing Scoop Catch by Myotis lucifugus. With fast-moving and maneuvering targets, especially, the bat apparently often finds it impossible or inconvenient to snare the target directly with the tail membrane, and certain bats may actually prefer to retrieve most targets with the use of a wing. Before the target is seized with the mouth, however, it is normally dumped into the forward-moving tail pouch with a sort of shovelling action of the wing.

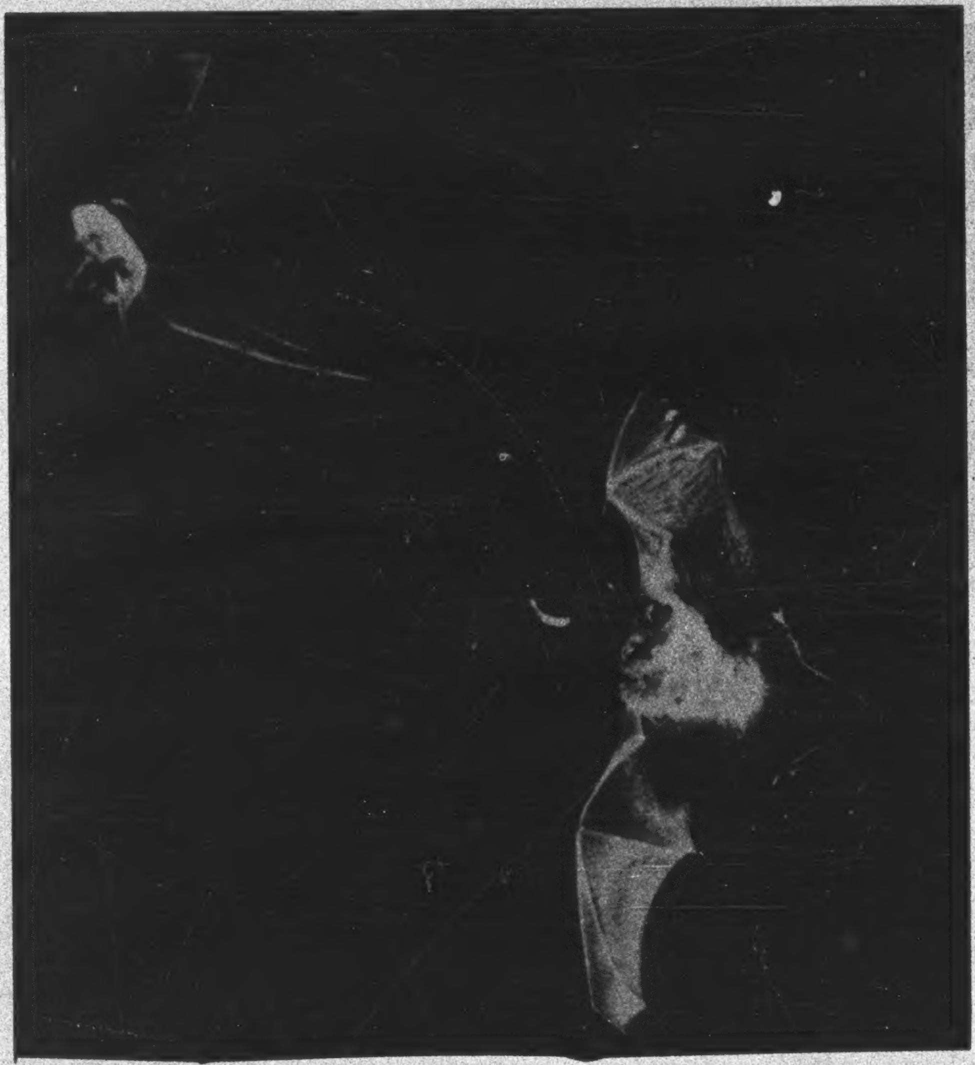


Figure 22. Wingtip Catches by Myotis lucifugus. Targets threatening to go quickly out of reach often result in a somewhat special kind of wing catch. In this Figure, for example, a falling target is just barely reachable with the tip of the wing. By bending the tip sharply over in advance of contact the bat prevents the target from slipping off the end of the wing. A rapid inward pull then puts the target in the tail pouch.

method. Prior to contact, the bat bends the tip of its wing sharply over; the wing is then moved in such a manner that the target either lodges directly in the groove so formed or slides there after contact. Sometimes the bat appears to make several separate motions of the wing while attempting to snag a target correctly. But once the target is lodged in the groove, the wing is pulled rapidly inward, thus bringing the target into the pouch formed by the forward-moving tail membrane. The insect is then brought to the mouth as before. Figure 24 illustrates well the extreme accuracy of aim often achieved with these wingtip reaches. Accuracy of localization at some distance is indicated in Figure 25.

Catches by Other Bats

Catch techniques used by other bats have also been photographed. By and large, these techniques (with some variations of emphasis or detail) correspond to the technique observed with Myotis lucifugus. The most notable exception thus far seen is the backward somersault catch of the red bat, Lasiurus borealis, described below. Other catches of interest are the following. The wingtip catch of an underwing moth by the Old World Horseshoe bat, Rhinolophus ferrum-equinum, described elsewhere,[18] is of chief interest

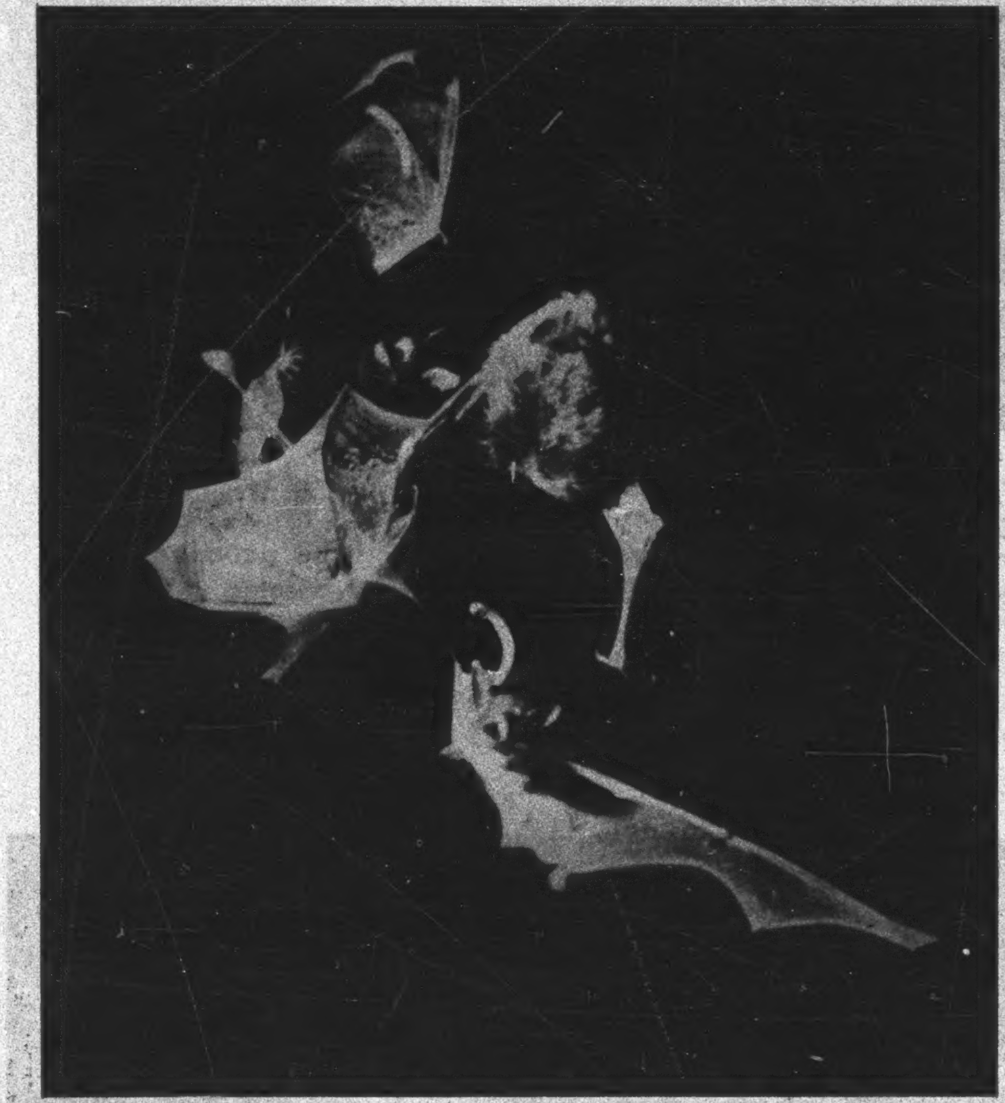


Figure 23. Wingtip Catches by Myotis lucifugus. Here we see a situation similar to that of Figure 22, with a target rising rapidly above the bat. Shadow indicates that the mealworm is just making contact with the wing.

because it illustrates that the very different signal system used by these bats still permits extreme accuracy of aim. Recent films have supported previous observations indicating extensive use of the wing membranes to execute catches, but have also shown that the use of the tail membrane is sometimes rather similar to that seen in Myotis. Myotis keenii, a close relative of Myotis lucifugus, appears to specialize in slow flight and extremely quick maneuvering. Three attempts at a target are sometimes made within one second. The large brown bat, Eptesicus fuscus, has not yet made catches of mealworms in the laboratory. A few pictures made outdoors suggest that its techniques of catch are very similar to those of Myotis lucifugus, but that its flight speed is higher. It appears to achieve very accurate aim toward its target at distances of 6 feet or more. One difference noted with Eptesicus bats is the apparent use of passive listening in the preliminary location of certain targets. These bats sometimes appear to be attracted to single buzzing insects and to swarms of smaller insects, even when not emitting pulses themselves. Whether or not they can home in on these sounds and achieve captures without the use of the usual terminal echolocating signals has not been established. Were this true, it would be interesting to know whether they also homed in on some of the noise-making moths which might be obnoxious to other bats but suitable food targets for

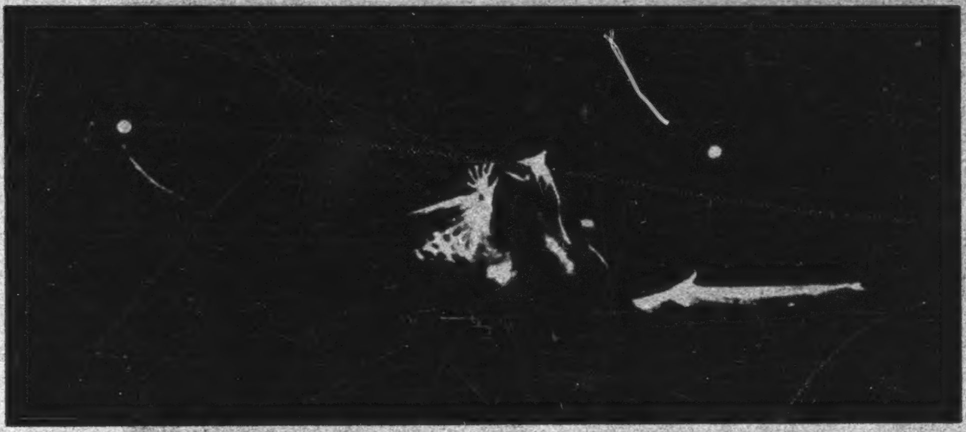


Figure 24. Wingtip Hit of Small Sphere by Myotis lucifugus. Extreme accuracy of localization of a 3 mm sphere is obvious in this picture. During the process of capture such small, hard targets tend to bounce around in the membranes and are often lost (as happened here) before seizure with the mouth. If caught, such targets may be chewed for some time before being recognized as inedible.

Figure 25. Accuracy of Aim at a Distance. Myotis lucifugus typically follow their targets very accurately with the aim of their heads from a distance of 3 feet (as here) or more. Similar aim at a distance of about 6 feet has been observed out-of-doors with Eptesicus fuscus.

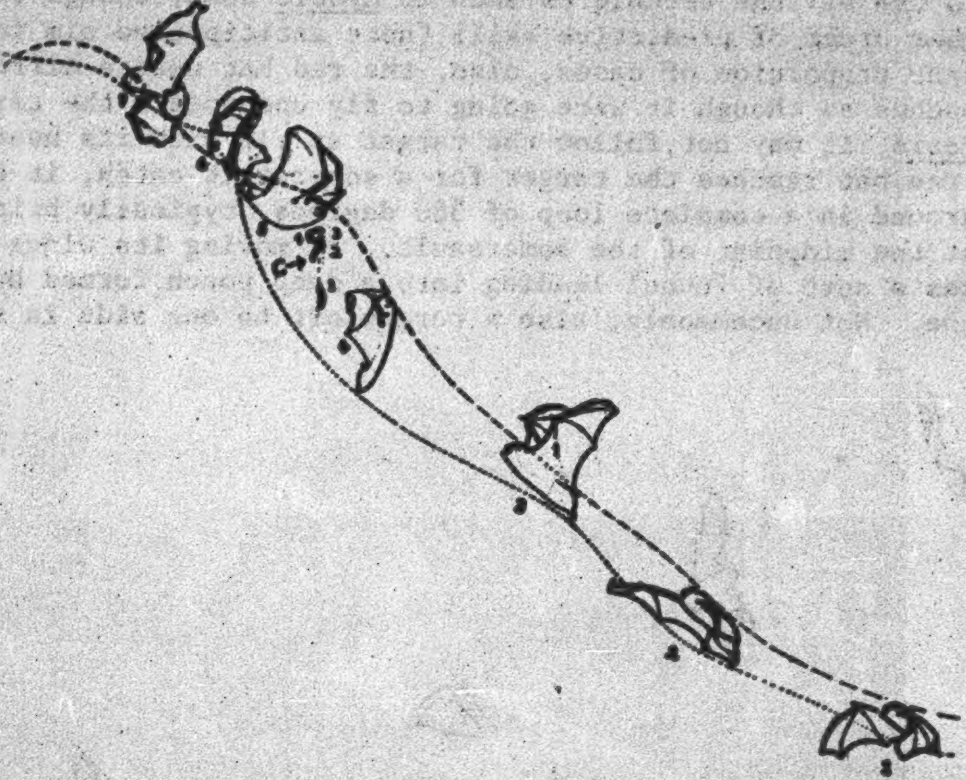


Figure 26. Somersault Catch by Lasiurus borealis. To show details of the action this sequence was made at 20 flashes per second instead of the usual 10. Finely broken line indicates path of the bat's tail, while coarsely broken line indicates path of the bat's head. Half a foot to a foot from the intercept point the bat puts its wings out and forward to provide counter-resistance for the rapid sweeping action of the tail which initiates the backward somersault. The wings are then brought together, still extended, and the tail membrane is formed into a deep pouch into which the target slides (if not initially caught there). Both wingtips are sometimes bent over, meeting in the middle, apparently to prevent the escape of a maneuvering target. The moving together of the wings, or the reaching out with a single wing, sometimes also serves to bring an offside target to the center. During the somersault the tail membrane may actually loop backwards, as here. Once the target is lodged in the pouch the bat appears to re-orient itself before reaching down for seizure. (In this catch one out of four mealworms was selected, but the other three were omitted for clarity.) C marks the point of capture.

Eptesicus. No systematic investigation has thus far been carried out on the manner in which such bats might combine the use of passive listening with echolocation.*

---

*Of considerable interest, with reference to passive listening, is the work of Payne on the accuracy of strikes by the barn owl. Rustling sounds, which include the requisite frequency band, permit the owl to localize a sound source to within one degree of angle (see Reference 21, particularly pp. 34-37 and 59-64). Evidence for accurate localization with high frequency sound components by human beings has been given by Batteau.[1] See also Mills.[19]

As mentioned above, the most notable exception to the catch techniques of Myotis ucifugus is seen in the somersault catch of the red bat, Lasiurus borealis. This bat as been observed to use all the techniques seen in Myotis bats, though often with what ppears to be a higher order of predictive skill (note anticipative aim in Figures 27 and 8). In a significant proportion of cases, also, the red bat uses a different technique. he bat often approaches as though it were going to fly underneath the target, Figure 26; oreover, unlike Myotis, it may not follow the target at all with its head and ears. bout the time the red bat reaches the target for a somersault catch, it suddenly swings ts tail membrane around in a complete loop of 360 degrees, typically bringing it to ero air velocity at the midpoint of the somersault. By moving its wings forward and ogether, it produces a sort of funnel leading into a deep pouch formed by the hind legs nd the tail membrane. Not uncommonly, also a target off to one side is shifted into the middle of this funnel by the bringing together of the wings, or sometimes by a shovelling action of one wing somewhat similar to that seen in Myotis. With the target lodged in the pouch, the bat comes out of its somersault, reorients itself, then reaches down into the pouch to seize its food. The evidence gathered with the only red bat tested in the laboratory suggests that this technique is more successful in the retaining of evasive targets and certain very small targets. One would be tempted to guess that the moving together of the wings and the rapid sweeping action of the tail membrane through the slot

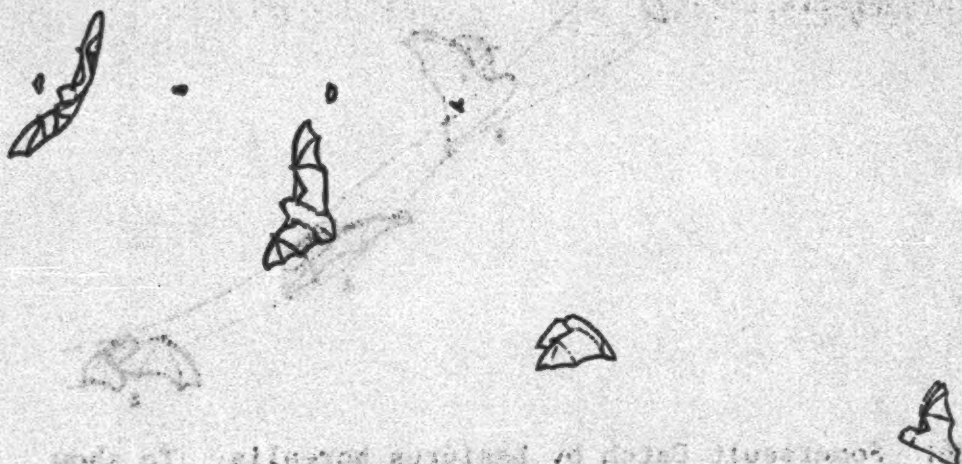


Figure 27. Interceptions of Moths by Wild Red Bats: Interception of Freely Flying Moth. The moth may have begun to turn away from the bat at the second flash, but no sudden evasion is made. (Traced from sequences made in conjunction with A.E. Treat.)

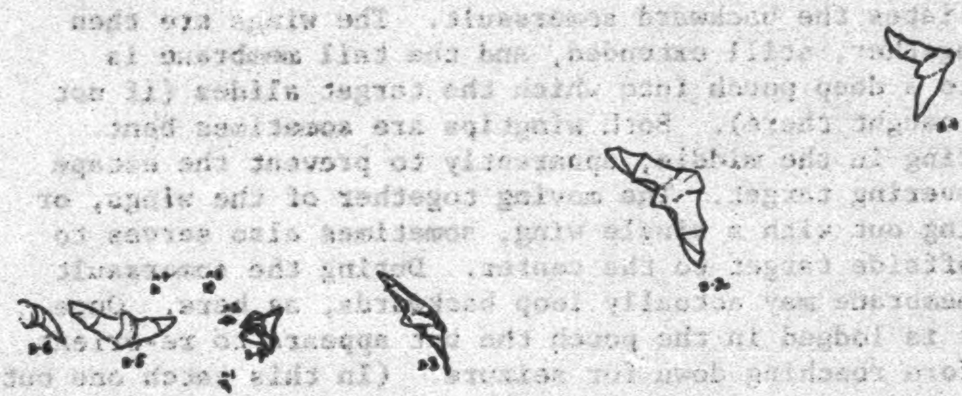


Figure 28. Interceptions of Moths by Wild Red Bats: Interception of Moth Tossed Up from Below. Despite some unevenness of trajectory due to the moth's initiation of flight, the bat appears to make a smooth and excellent prediction of the moth's path.

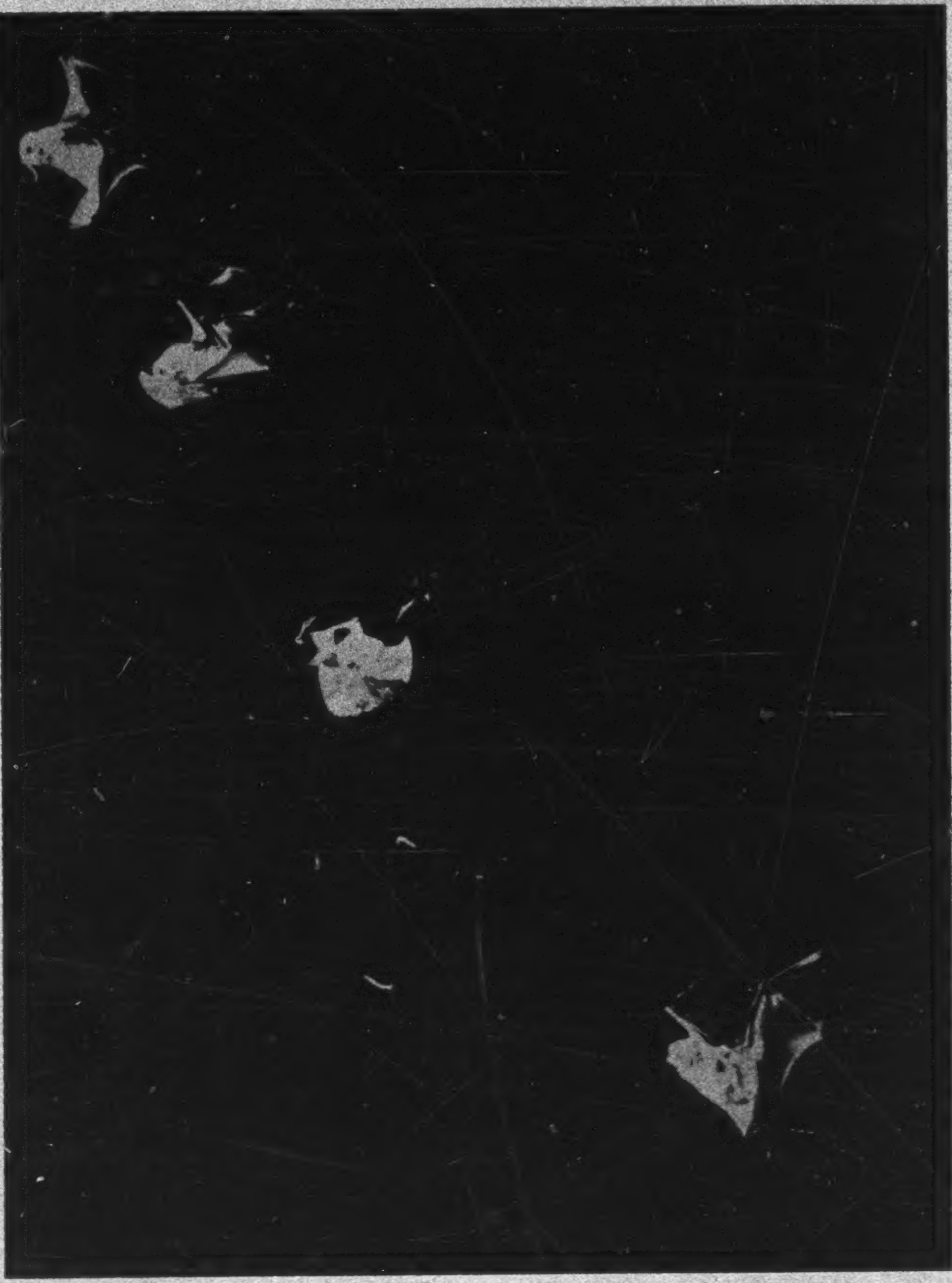


Figure 29. Nonsomersault Catch by Red Bat. This catch is very similar to the typical tail membrane catch of Myotis lucifugus. The last image shows the mealworm in the bat's mouth.

or funnel so formed was well designed for the capture of evading moths, where the moth's last-instant maneuvers may prevent precise aim by the bat during the final phase of pursuit.

Certain features of the red bat's performance deserve mention. For example, the one red bat tested has proved extremely proficient at the selection of one target from a cluster of as many as a dozen or more other nearby targets (Figures 10, 11, and 12). The precise and rapid retrieval of the selected target from amongst several others, closely observed in high speed films, indicated clearly that the bat did not simply fly into the cluster and grab what it happened to hit. Another notable feature of the red bat's interceptions is its capacity to intercept a rapidly falling target, even near the ground. Its success at some of these high speed captures appears to derive from three things:

1. The red bat has very strong wings and can accelerate rapidly.

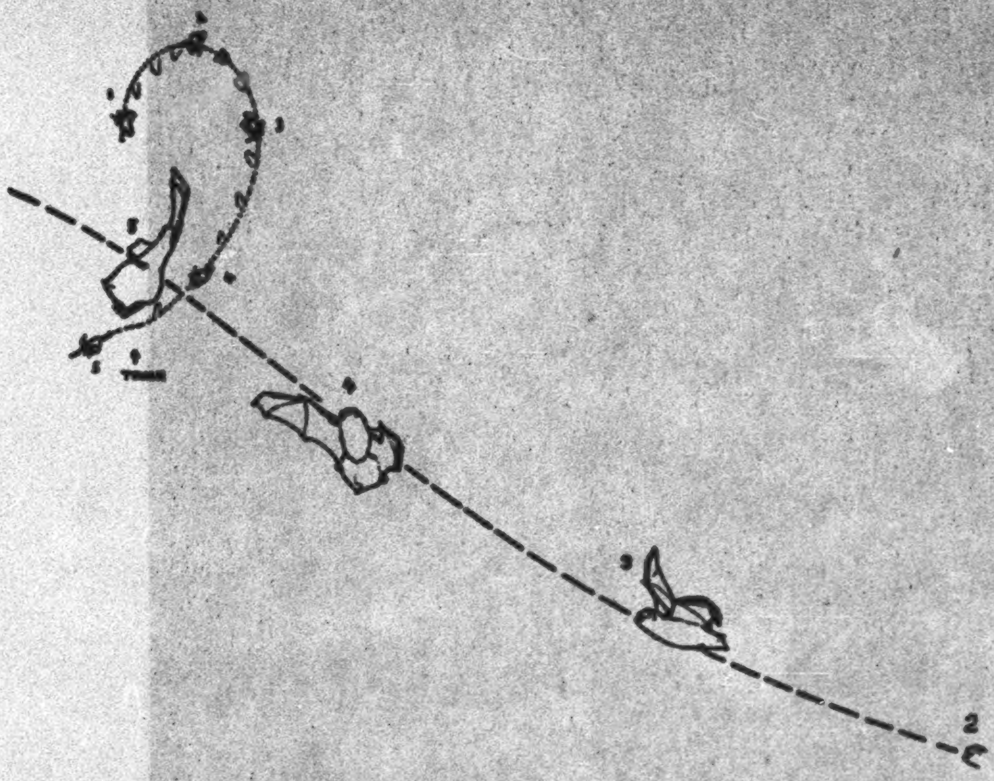


Figure 30. Wing-Touch of Tightly Spiraling Moth by Lasiurus borealis. Perhaps the most notable feature of this and some other similar sequences is the absence of radical following of the target typical of Myotis lucifugus. In this case the bat appeared to judge the approximate point to which the spiral or loop would bring the moth. The bat's left wing was rather seriously injured prior to this attempt and this presumably accounted for the fact that the scooping action of the wing resulted in a touch rather than a catch. Dotted markings indicate wing action of moth, here at about 40 beats per second.

2. It appears capable of predicting the optimum point of intercept for a rapidly falling target.

3. It seems able to make a good evaluation of the situation at some distance. The various features of the red bat's interceptions and catches are illustrated in Figures 10, 11, 12, 27, 28, 29, 30, 31, and 32.

Summary

The present section was intended to answer, in part, the question: How do bats catch? Broadly speaking, the evidence indicated that bats know accurately where their targets are, and that their techniques of catch are designed for a balance between certainty of catch and speed of execution. With smaller targets many bats seem to be able to aim so precisely that their mouths go directly to the intercept. Accuracies within plus-or-minus a half-centimeter appear typical. The tail membrane either assures that the target will not escape or aids in the actual catch. It is also far safer for the bat to strike large targets with a flexible membrane rather than with the mouth. For targets further from the direct flight path of the bat, the wings are used to pull or shovel the target into the tail pouch. Sometimes a rapidly moving target, or one that is detected at the last instant (or perhaps maneuvers violently), appears not to be precisely followed during the last fraction of a second. The mechanism of catch, however, tends

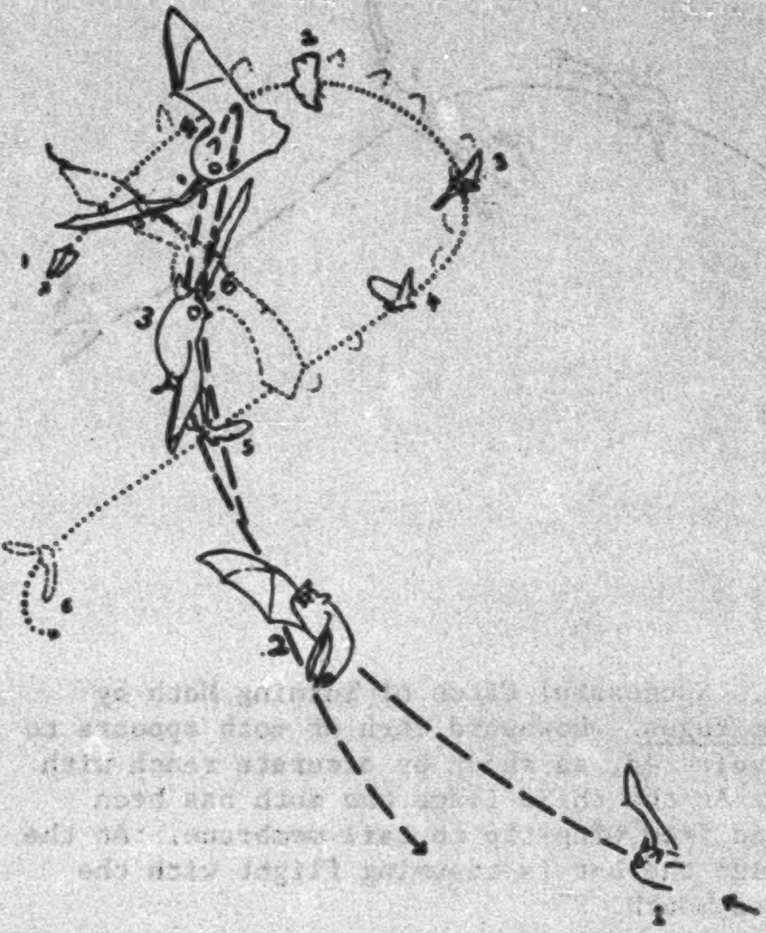


Figure 31. Attempt at Maneuvering Moth by _Myotis lucifugus_. In contradistinction to the rather nonspecific head following of the red bat, _Myotis lucifugus_ typically attempts to follow a target's maneuvers in detail. Possibly this servo-action works poorly at high angular velocities or accelerations, or the bat is unable to profit from the indications. In this instance, certainly, the action of the bat's body lags so seriously behind the moth's maneuver that the bat relinquishes pursuit.

to funnel the target into the center of the tail pouch, and although such indirect techniques of catch may take more time, they are ordinarily successful.

The rates at which bats can catch small targets, such as fruit flies, have been discussed elsewhere.[14] As many as two complete catches and perhaps as many as three attempts within one second seem not uncommon. Sustained rates of about 15 catches of fruit flies per minute have been observed in the laboratory. If such a rate were sustained for an hour, the number of insects caught would be about 900. Except in the case of evading moths, the reliability of catch is sometimes extraordinary. Estimates suggest that 95 percent of fruit flies attempted are sometimes caught. In one series of tests, a bat made over 100 successive catches of mealworms tossed into its flight path without a failure, despite the fact that many tosses were far from perfect and that difficult selections from possible alternative targets were often required. In summary, the bat's typical catches can be described as extremely rapid, astonishingly accurate, and sometimes almost unbelievably reliable. The general rule of procedure seems to be that the bat heads accurately for the target, or the expected point of intercept, but has at its

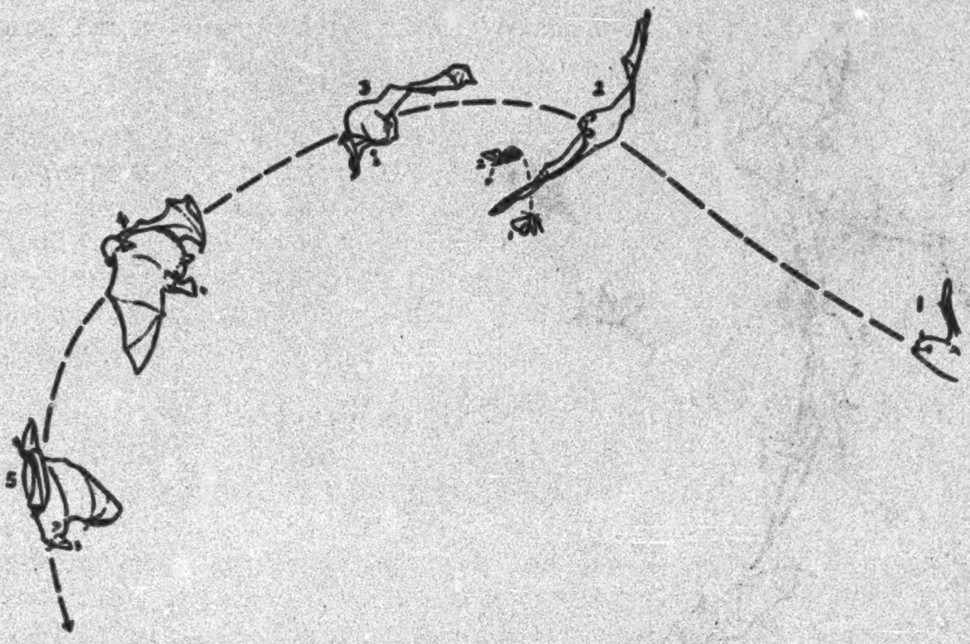


Figure 32. Successful Catch of Turning Moth by Myotis lucifugus. Downward turn of moth appears to be well evaluated, as shown by accurate reach with the wing. At the third image the moth has been transferred from wing tip to tail membrane. At the fourth image the bat is resuming flight with the moth in its mouth.

command techniques of catch capable of compensating for many of the last-instant maneuvers that introduce radical displacement of the target from the expected point of catch.

WHAT CAN A BAT JUDGE ABOUT ITS TARGET IN ADVANCE OF CAPTURE?

Initial studies have suggested that the identification and selection of targets is not only a very complex problem in itself but that its experimental evaluation is fraught with complications. To cite an example: A Myotis lucifugus was being tested for its capacity to discriminate between mealworms and a rubber disc which, when seen end on, appeared about the same size as a mealworm, but which obviously gave much greater reflected echoes when at right angles. During an early phase of the experiment the average scores taken over all tosses of targets was such that no significant discrimination was evident. Closer scrutiny, however, revealed that when the bat was hungry it almost invariably selected mealworms and when adequately nourished it almost always chose the discs. Although the bat was clearly capable of almost perfect discrimination, a casual survey of the results suggested no discriminating ability at all. In many other of the tests, the bats undoubtedly had an excellent capacity to discriminate between the various targets encountered; yet since all were harmless, the bats caught whatever appeared. Indeed, complete suppression of the inclination to catch (by a hungry bat) requires negative reinforcement. Thus, when the red bat was presented with various sizes of spheres, it caught almost everything from a 2-1/2 mm shot to a 70 mm tennis ball of 25,000 times the volume. Nevertheless, certain results, including some later tests with the same bat, suggested very striking discrimination capacities. One Myotis bat learned quickly to make perfect discrimination between mealworms and all sizes of spheres when each target was presented singly. In sample tests this bat also showed ability to discriminate between mealworms and cylinders that must have given very similar echoes. Only when an object approximated almost exactly the size and shape of a mealworm was no discrimination evident. Impressive selections of mealworms from several simultaneous alternative targets were also sometimes achieved.

To gain a preliminary idea of how the echoes from spheres and mealworms sounded to human observers, recordings were made of the echoes returned by these targets. Bat-type pulses were directed at the spheres and mealworms from a distance of one foot, and the echo recorded on tape at 60 in./sec. The tape was then slowed down to a playback rate of 1-7/8 in./sec, 32 times as slow. To prevent masking of the echoes, the outgoing pulses were gated out. Even under these rather ideal conditions, however, the echoes from mealworms and spheres of corresponding size sounded essentially similar to the human auditory system.

These tests were so preliminary that no final conclusions can be drawn. There is nevertheless a clear suggestion that the bat's system is far better adapted to the required kind of analysis than is the human auditory system, and can function at many times the speed. Suitable preprocessing of the echoes of course might radically alter this situation, the use of beat patterns being one obvious example. Such experiments might also give useful clues to effective echolocation procedures for the guidance of blind persons. What we learn from the methods of bats may tell us a great deal about what is possible with echolocation methods and may even suggest procedures whereby such methods could be implemented.

In summary, bats are capable of excellent identification of simple laboratory targets (e.g., spheres, cylinders, discs, and mealworms) within the fraction of a second between detection and capture. Decision to avoid an inedible target is accompanied by an immediate cessation of the rising crescendo of pulses leading to the catch. Identification, however, seems typically better than the related action observed. Bats often catch any airborne object of suitable size that is presented, even when it is known to be inedible; at times they even select an inedible over a simultaneously presented edible target which they can clearly distinguish.

Virtually nothing is known about the details of natural targets that may be evaluated by a bat. Wing action is perhaps the most obvious feature that might provide crucial information both as to the nature of the target and its expected maneuvers. Other features include such items as size, structure, texture, and relative orientation. Analysis of many such features is complicated by the large number of interrelated variables.

HOW ARE THE BAT'S ECHOLOCATING SIGNALS RELATED TO THE INTERCEPTION PROBLEM BEING UNDERTAKEN?

Just how the bat's echolocation signals are related to the evaluation and interception of targets appears to be a very complex matter with many obscure facets. The general nature of the interception signals of certain bats has been well described by Griffin.[7,8] Because the present studies have been limited to interceptions by two kinds of bats, the discussion will deal chiefly with these two bats: Myotis lucifugus and Lasiurus borealis. Also, since details of the signals of these bats have been discussed elsewhere[8,14,16,17,34] the possible significance of many features will not be touched on here. The present discussion is limited to a rough analysis of how the signals change as the bat intercepts and catches its prey.

The Interception Signals of Myotis lucifugus

The hunting signals of these bats are conveniently described in terms of three phases:[14,39] 1) search, 2) approach, and 3) terminal phase. Probably the easiest way to picture how the signals shift during the course of an interception is in terms of the two extremes: the search phase and the terminal phase. During the search phase the pulses are relatively long and occur with considerable spacing, though the spacing may be somewhat irregular. During the terminal phase, or "buzz," the pulses are very short, occur in rapid succession, and with very regular spacing. It seems likely that the echo from a single search pulse can provide adequate data for the initiation of oriented pursuit behavior. By contrast, the echoes from buzz pulses are probably analyzed in groups.

In the laboratory the search pulse of a Myotis lucifugus bat has a duration of 2 to 4 milliseconds (most commonly about 3) and recurs with a spacing that tends to run from about 50 to 100 milliseconds--in other words, at roughly 10 to 20 pulses per second. Each pulse starts at a frequency of about 100 kilocycles and falls fairly uniformly over about an octave, ending at roughly 50 kilocycles.*

Upon detection of a potential target or a nearby obstacle, the interval between pulses tends to decrease and the pulses tend to shorten. If the object is something to be pursued, the bat enters the second, or approach, phase. Pulse repetition rate goes up progressively, but often very irregularly (sometimes with interesting pulse groupings), merging within a quarter to a tenth of a second into the terminal buzz. During the approach phase, pulse duration also shortens, but often not in a uniform way. The frequency span swept by the pulse at first tends to remain approximately an octave (sweeping from 100 kc to 40 or 50 kc), but soon begins to slide down to lower frequencies. The rate of frequency sweep, of course, tends to increase as the pulse length shortens. When slowed down for human listening, the series of transition pulses often gives a momentary impression of uncertainty, then picks up speed in a positive way and leads into the terminal buzz.

The buzz pulses of a Myotis lucifugus typically have a repetition rate of 180 to 190 pulses per second, the total buzz consisting of anywhere from about a dozen to perhaps two dozen pulses, from one-third to one-half a millisecond in duration. The frequency sweep tends to be greatly reduced, often running below 30 kilocycles at the pulse front, and sweeping down as little as 5 kilocycles. Because the pulses shorten as the repetition rate goes up, the duty cycle may not be significantly altered, tending to remain of the order of 5 to 10 percent.

In analysing the relation between the bat's emitted signal and the interception problem being solved, perhaps no single item is of greater interest than the spacing between a given outgoing pulse and the primary echo. Were the bat to attempt accurate range determination by direct measurement of the time between the emitted pulse and the corresponding portion, theoretical analysis,[17,22-24] has suggested that the results could not provide the requisite accuracy, particularly with weak echoes. On the other hand, if the emitted pulses occurred in well standardized units, and a technique were used which introduced overlap between some representation of the returning echo and of the outgoing pulse, greater precision might be achieved. This contention is debated with significant neurological evidence, however, by Grinnell.[15] Preliminary measurements thus far made with Myotis pulses indicate that direct overlap normally does not occur. Instead, a gap of one or more milliseconds seems typically to be left between the end of the emitted pulse and the beginning of the returning echo of chief interest. As the bat gets closer to its target, the pulse shortens so as to keep the returning echo out of the overlap zone. An illustration of these relations has been given by Webster,[38] and a further illustration is presented in Figure 33.

---

*In the present illustrations, frequency is indicated by use of a zero-crossing meter which moves up one centimeter for zero-crossing intervals running from 100,000 to 50,000 per second, another centimeter for frequencies running from 50 thousand to 33-1/3 thousand, another centimeter for frequencies running from 33-1/3 thousand to 25,000, and so on (as in Figure 41). The line representing the increase of zero-crossing interval (decreasing frequency) is essentially straight for many of the pulses, suggesting that the shift in frequency tends to be more or less hyperbolic.

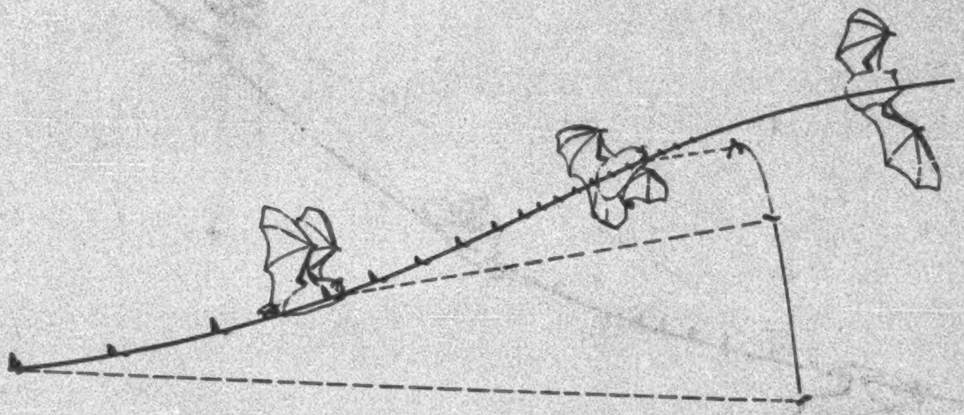


Figure 33. Relation of Emitted Signal to Pursuit Action in Myotis. During this relatively straight interception the bat reduced its speed very little. Of particular interest are 1) the position of the terminal "buzz" relative to the intercept point, and 2) the relation of emitted pulses to returning echoes. The buzz, which here consists of only 9 or 10 pulses, does not start until the bat is about 10 inches from its target. It continues almost to the point of contact (and in Figure 20 continued briefly after contact). The position of the returning echoes relative to the outgoing pulses is easy to calculate, since the sound goes out and back about 6-3/4 inches (17 cm) per millisecond. Either an electrical or an acoustical disturbance appears on the sound record with each flash, and is used (with correction for acoustical delay) to establish synchrony. Outgoing pulses are shown on the upper side of the flight line, returning echoes below. Pulse length is shortened to keep primary echo well out of overlap zone (i.e., primary echo is out of zone of overlap of pulse being emitted).

The echo relations seen in adult Myotis bats, however, do not preclude the use of direct overlap in the signals of other vespertillionid bats or during the course of development of echolocating techniques by young Myotis bats. (The possible occurrence of "secondary overlap"--overlap between a pulse being emitted and the echo returned by the previous pulse--is illustrated in Appendix Figure 52 during pursuit by the red bat.) Moreover, as already mentioned, the Old World Horseshoe bats emit pulses of such a length and duty cycle that most of the echoes must come back while the pulses are being emitted. As will be shown below, these bats appear to have special techniques to help resolve the problem. Even with Myotis bats pulse overlap may be used for exclusion measurements, that is, to indicate the range of nearby objects which are to be avoided during the course of pursuit. Also, the possibility that some bats may intermittently emit low level "probe pulses" for intentional interaction between outgoing probe and returning echo has never been excluded. At this juncture, however, the manner in which a bat uses the indications from returning echoes is so inadequately understood that we can say very little. How the bat derives the various categories of information that it needs to achieve the rapid and successful pursuits so commonly seen will call for much more extensive study.

The Signals of Red Bats

Basically, the pursuit signals of red bats (Figure 34) are quite similar to those of Myotis lucifugus. The chief differences can perhaps be summarized as follows:

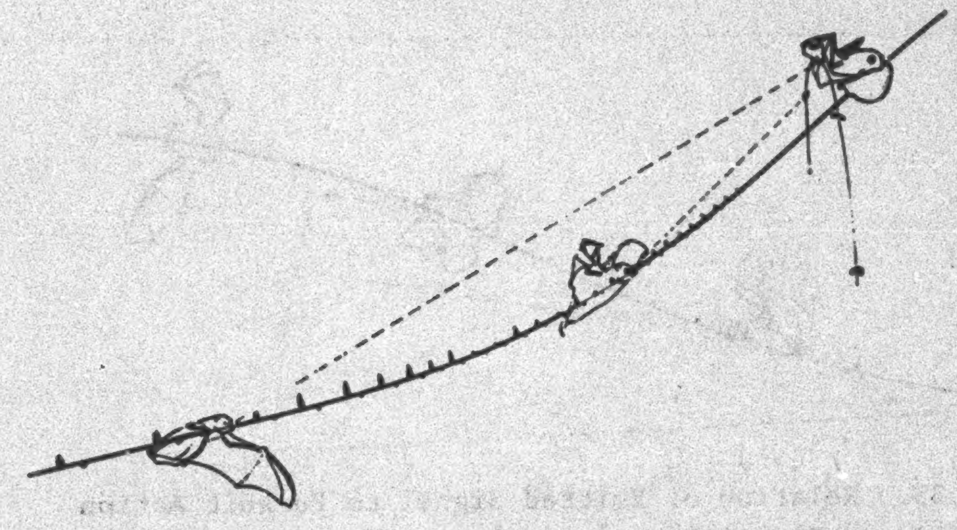


Figure 34. Relation of Emitted Signal to Pursuit Action in Lasiurus. This pursuit was chosen for comparison because of its general similarity in form to Figure 33. Besides the typically higher initial approach speed, features of interest are 1) the longer and more distantly placed buzz, and 2) the resultant positioning of the echoes closer to the center of the interpulse interval. The buzz starts just over two feet away, and ends about five inches from the point of contact. Though in most cases the returning echoes are closer to the corresponding emitted pulse, they sometimes occur beyond the center of the interval and may lead to secondary overlap (i.e., with succeeding pulses). The apparent terminal speed-up of the pulses is actually due to the slowing of the bat. Further comparisons are given in Figure 35.

1) The outdoor cruising pulse of the red bat is considerably longer than that of Myotis, often reaching about 10 milliseconds in duration.

2) While the frequency structure of the cruising pulse (except for a flat terminal portion) corresponds roughly to that of the Myotis pulse, the structure changes very little in the transition from cruise to buzz (the upper frequencies dropping only from about 85 or 90 to perhaps 60 or so). There is, of course, a definite steepening of the sweep rate as the pulses shorten.

3) More sudden and pronounced variations sometimes occur among such features as pulse amplitude, pulse shape, pulse duration, and interpulse interval.

4) Longer buzzes (exceeding 30 pulses in length) are not uncommon.

5) Secondary overlap (i.e., with echo from previous pulse) may sometimes occur during pursuit.

Some of the variations in pulse patterns, during interceptions, are shown in Figures 35 and 36. There is a possibility that the red bat uses the backward somersault technique when it expects an interception of some difficulty or complexity. There is evidence that the red bat may make somewhat different use of its signal indications than does Myotis lucifugus, but just what such differences actually are remains to be determined.

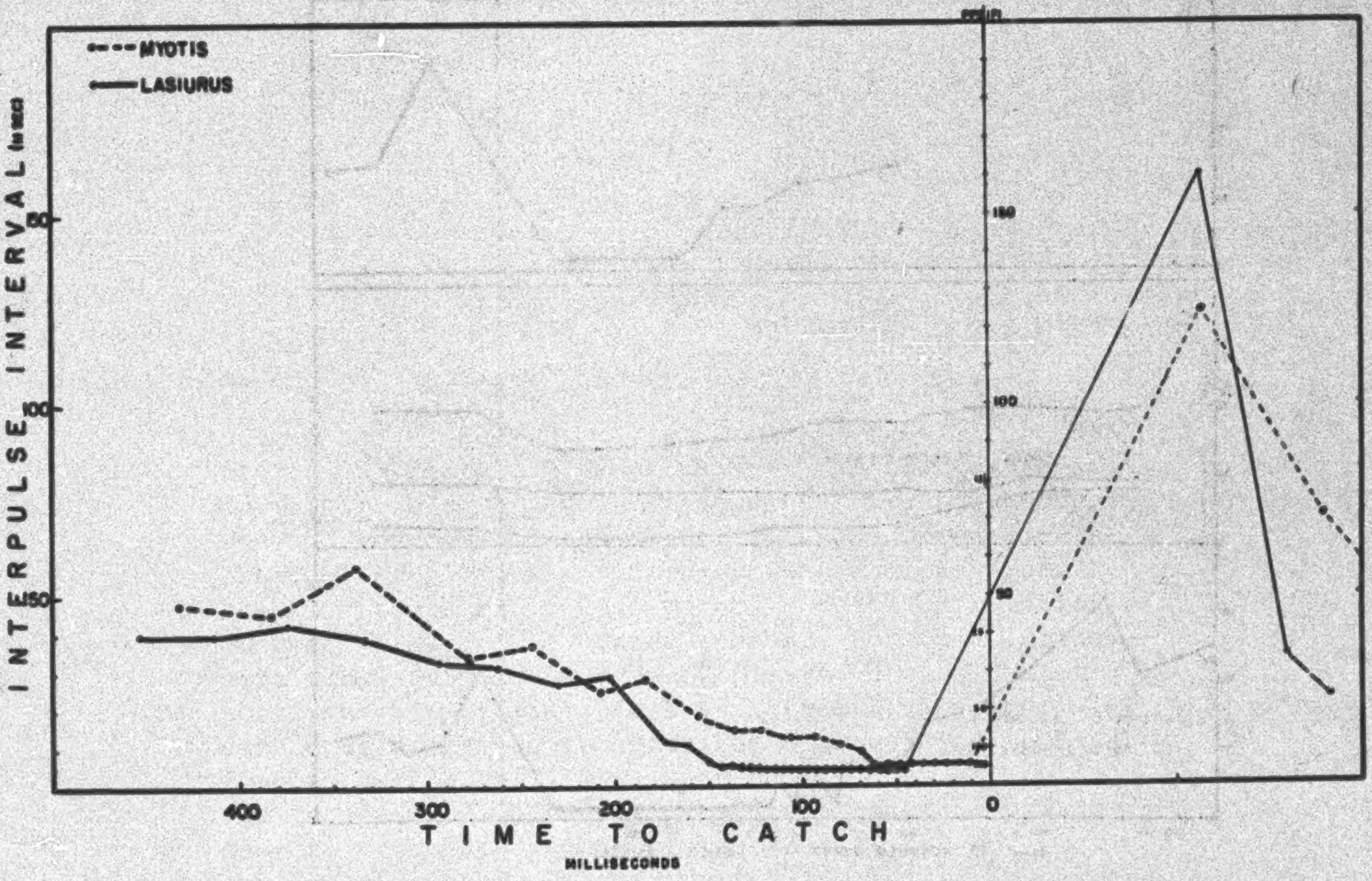


Figure 35. Pulse Patterns During Interceptions. Pulse repetition patterns for the catches illustrated in Figures 33 (*Myotis*) and 34 (*Lasiurus*). The ordinate is interval between pulses, in milliseconds, and the abscissa is time to contact with target, also in milliseconds. One convenient way to visualize the indications of these plots is to imagine a diagonal sweep (of uniform rate) starting at the base line at the beginning of each pulse, a given sweep terminating when the next pulse occurs. Both ordinate and abscissa spacings are thus linearly related to interpulse interval. Possibly the most conspicuous feature of difference between the *Myotis* sequence and the *Lasiurus* sequence is the fact that the long terminal buzz of *Lasiurus* has almost ended before the terminal buzz of *Myotis* has started. Though such a large discrepancy may not be entirely representative, and extensive individual variations also occur, it is to some extent typical of one major difference in the approach signals of the two kinds of bats. Another obvious difference in the repetition rate of the terminal pulse sequence (buzz). For the *Myotis* record the rate is about 180 pulses per second, and for the *Lasiurus* record, about 218 pulses per second. Other records of these bats (some made in the wild) have shown like differences. The long pause after the catch occurs because the bat's head is down in the pouch for seizure of its prey. An unsuccessful attempt or re-orientation prior to seizure with the mouth results in a shorter pause. (Other records of the signals associated with interceptions and attempts are given in References 7, 8, 14, 15, 31, and 38.)

The Signals of *Rhinolophus ferrum-equinum*

While adequate studies of *Rhinolophus* bats during pursuit have not been completed, some synchronized recordings and high speed films have been made of *Rhinolophus* bats landing[9,25] and catching mealworms. The landing films showed that during the final part of the approach (in one instance at least) pulse repetition rate increased to about 80 per second. During pursuit, rates up to 88 per second were noted. However, in contradistinction to the FM bats discussed above, the duty cycle remains so high

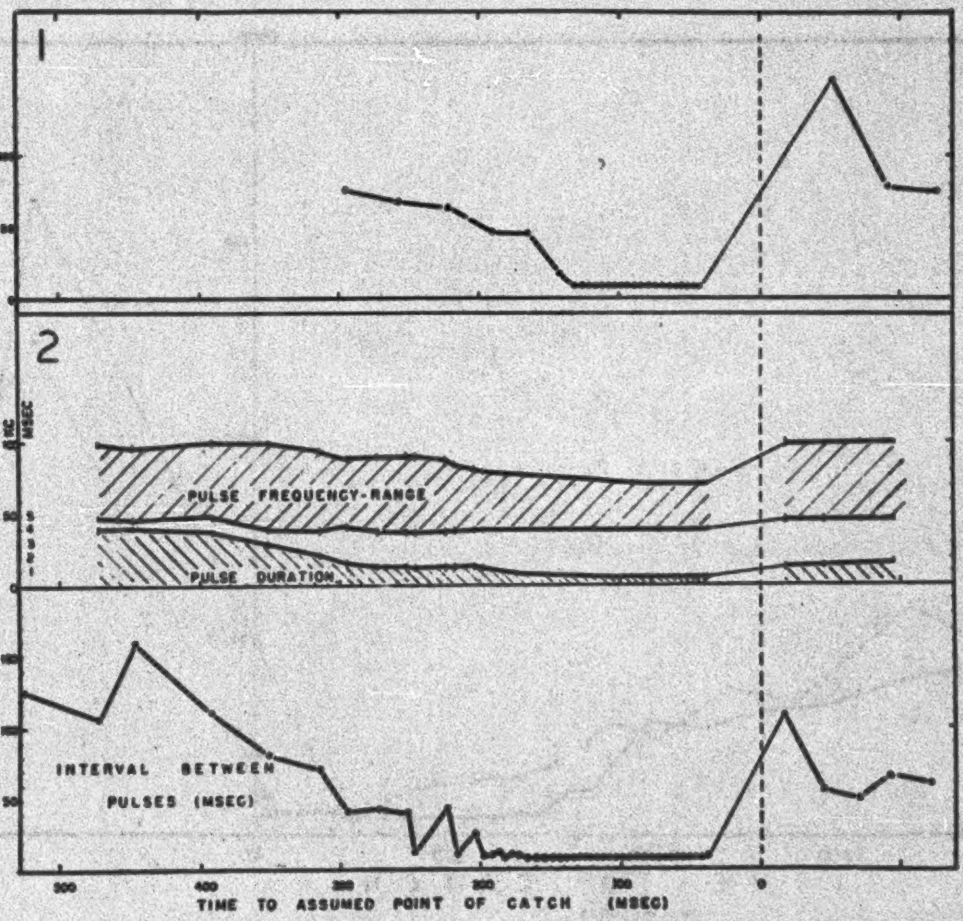


Figure 36. Pulse Repetition Patterns During Catches by Lasiurus borealis. The two sequences shown here were chosen because they approximated two extremes of the interception signals for catches by Lasiurus in the laboratory. The first illustrates a definite and relatively uniform transition into the terminal sequence, while the second shows a transition with alternation of longer and shorter spacings and some irregularity at the start of the long buzz. Current evidence is inadequate to specify the significance of the alternating or irregular groupings and long buzzes that sometimes occur. One guess is that they may be related to selection or location of a target in a complex situation (complex nearby configurations, multiple targets, irregular target motion, etc.). Pulse gaps in the sequence, as seen in the signals of Figure 12, are also common. Above the pulse interval plot for Number 2 are plots giving a rough indication of pulse duration and frequency range. The chief feature of note relative to corresponding records of Myotis, is the continuing rather high initial frequency and large frequency sweep throughout the buzz. Differences between sequences in the laboratory and in the wild may be seen by comparing a typical outdoor sequence (Figures 52, 53, and 54) with the present records.

(approximately 90 percent) that most echoes must continue to be received during the emission of pulses. Adequate time reference between pulse and echo probably could hardly be established in a positive way without additional measurements than simple echo time. The most notable additional feature of the signal reception system of this bat is the

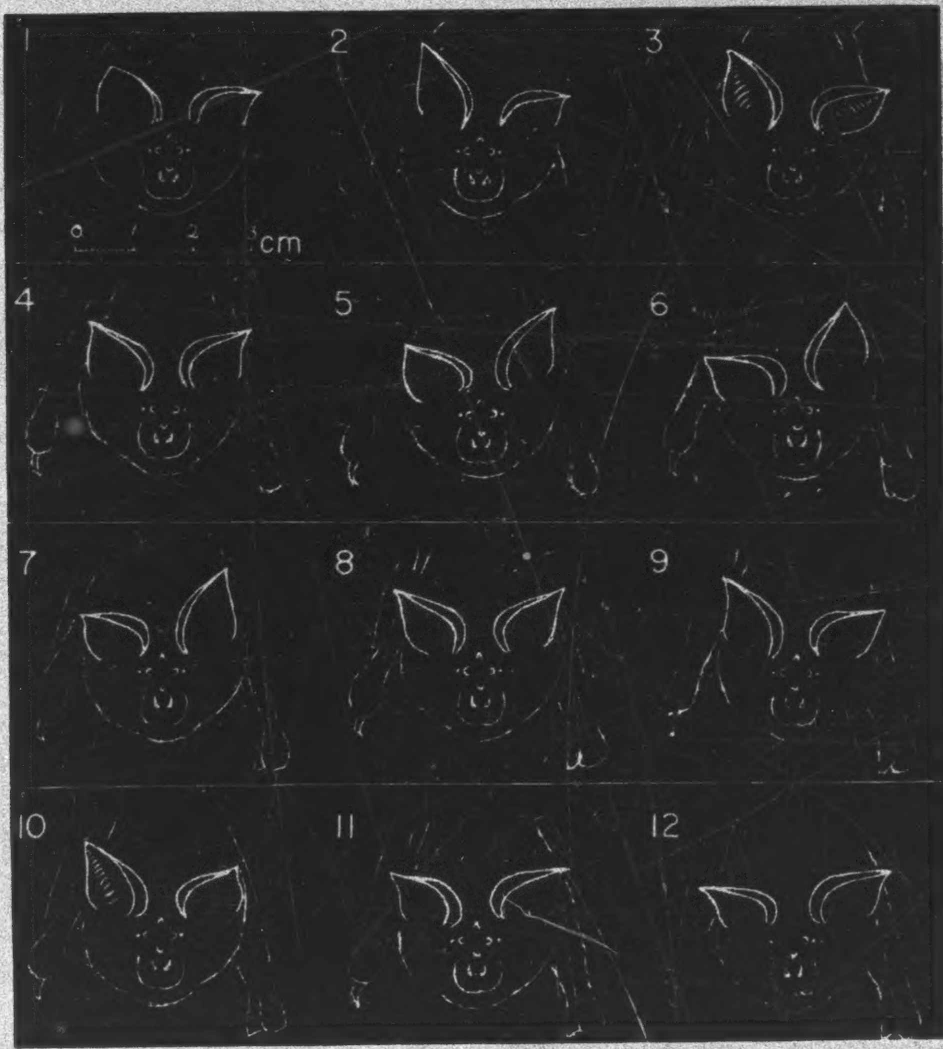


Figure 37. Ear Alternation During Inspection of Close-up Object. This illustration is the start of alternation in film sequence 105-5 of Reference 9. At frame Number 1 the right ear is just starting back after the head has been moved forward in a scanning action with both ears symmetrical. The first pulse of the present group of eight ends as the right ear reaches its full back position (see frame Number 3) and another pulse starts, about four milliseconds later, roughly as the right ear moves forward again. This pulse ends (about 25 milliseconds later) when the ear positions are reversed (see frame Number 6). There is a sudden increase in rate after the first three pulses, but ear action and pulse timing remain well synchronized during the five yet more rapid pulses that follow. At this point the synchrony breaks up and a new phase begins. (The interval between frames is 7.8 milliseconds.

occurrence of rapid oscillations of the ears. Various kinds of oscillatory action have been described,[33] the one of most immediate interest being the accelerating alternation of left and right ears seen during the bat's approach to a landing, during most pursuits, and also seen when an object is brought up close to a stationary bat. Examples of this oscillatory motion are shown in Figures 37 and 38. Of special interest is the fact that, during part of this rapid oscillatory phase at least, there is an almost exact one-to-one correspondence between each pulse (which is emitted through the nose) and a specific action of the ears, though the phase relations between the two may shift. Apparent onset of alternation during decision between two targets is shown in Figure 38. Various

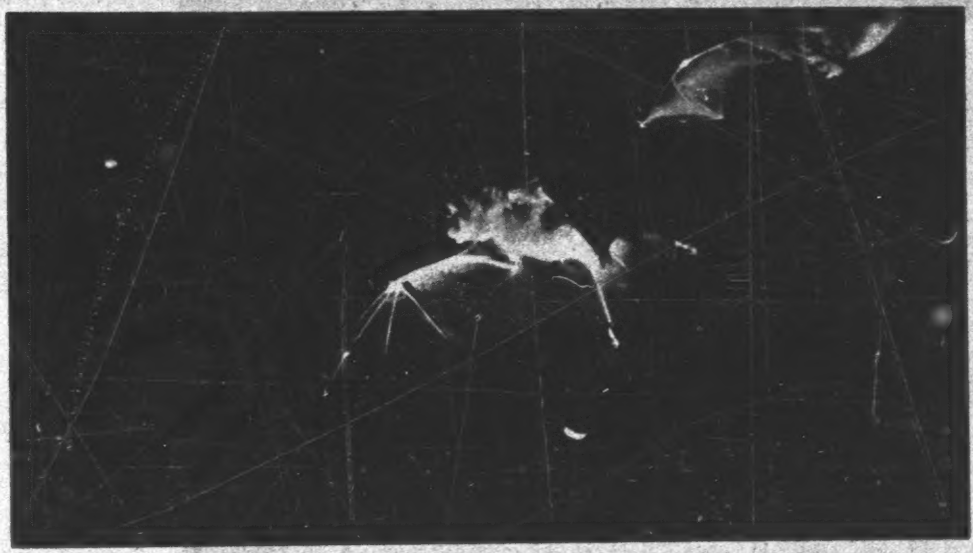


Figure 38. Ear Action During Decision between the Pursuit of Two Targets. Ear action in these bats appears to vary greatly during the final phases of pursuit. Sometimes, ear alternation continues to the point of catch; at other times the alternation diminishes in excursion until both ears are directed forward symmetrically from a distance as great as a foot away from the target. Catch techniques are highly diversified and commonly involve extensive use of the wings. In one of the current sequences, for example, the target was passed from the left wing to the right wing and back to the left wing again for seizure with the mouth. In contradistinction to the evidence of previous investigators,[40] current high speed films indicate that the tail (interfemoral) membrane is sometimes used, either directly for the catch or in conjunction with a wing, prior to seizure by the mouth. The present illustration is a two-flash sequence showing what appears to be the transition from the ear-forward approach (commonly seen at close range to a target) to the alternating ear inspection of a more distant alternative target, which was caught.

implications of this mechanism have been discussed elsewhere, and need not be described here. One relevant point to note, however, is that either the neurological "commands" to the ears, or the proprioceptive indications of such action, may provide the requisite time reference on which the bat anchors measurements of range. This appears to be but one more example of the many ingenious mechanisms that evolution has produced to provide bats with the extraordinarily rapid, precise, and reliable echolocation techniques which current studies have amply demonstrated.

Summary

Existing knowledge of the relations between the echolocating signals and the interception procedures governed is not adequate for proper summary. A few general comments can, however, be made.

1) Definite relations exist between aspects of the bat's emitted signals and certain definable features of the interception situation. For example, pulse repetition rate and pulse duration are related to distance to target and phase of interception. (Since interception velocities vary by a factor of at least 10, distance and phase are not equivalent.) In the temperate New World bats pulse length appears to be shortened so as to avoid primary overlap between emitted pulse and returning echo. Repetition rate may increase by a factor of 100 between the phase representing search for a distant target and the terminal phase immediately preceding a catch (for example, within one foot). Even in the Old World Horseshoe bats, which use pulse overlap, terminal rates may reach almost half the maximum rates seen in typical New World bats, the latter typically approximating 200 pulses per second.

2) There is some evidence that features of the emitted signal are related to difficulty, or expected difficulty. Irregularities in repetition pattern and perhaps in pulse structure often appear to increase in such situations. Prolongation of the approach phase or terminal phase may also occur.

3) The decision to relinquish an attempt at interception, or to defer final approach pending a preparatory maneuver, is accompanied by an immediate drop in repetition rate.

4) The rapidity with which the emitted signal can be altered in accordance with sudden changes in the interception situation is not established. Shifts with unexpected events do, however, sometimes seem to take place in one-twentieth of a second or less.

5) Certain receiving mechanisms (the aim of the outer ear, for example) are strongly related to signal emission (or to expected echo) in some bats. In others little external action is evident. There may however be many features of the ear mechanism which present observations overlook.

CONCLUSIONS

In concluding, an attempt must be made to answer the question, "What do interceptions by bats have to do with the guidance of blind human beings?" In broadest terms, a suitable general answer might be this: The echolocating procedures of bats during interceptions bring out the bat's techniques at peak performance. The study of the bat's peak performance may reveal details, methods, and principles normally masked in the less exacting tasks which might seem more logically related. Certain aspects of the problems interpose obvious difficulties when attempts are made to convert the findings in bats to the development of methods for human beings. For example:

1) Attempts at direct application of the bat's signals to human use tend to be disappointing, even when suitable frequency conversions are made. The bat's system was designed for different problems and probably with quite a different processing emphasis. At the same time, a knowledge of how the bat processes its echolocation data might well provide extremely valuable clues for methods adaptable to human beings.

2) The acoustical guidance of bats is dominated very heavily by the requirement of speed. The focal point of a bat's system, perhaps, is its capacity to guide pursuits of small and rapidly moving targets. In studying the bat's system, as used in other applications, the dominant role of this particular function in the evolution of its methods must constantly be kept in mind. Possibly the bat's system can give many clues to acoustical guidance where speed is important. Taking clues from bats, for example, highly effective methods might be developed for effective blind guidance during such sports as tennis, volley ball, trampolining, and skiing.[38]

There is a final point which is especially worthy of note. The bat's mechanisms are ultra-miniaturized. The bat's extraordinary achievements are done with analytical quipment that may weigh only one-tenth of a gram. The bat, moreover, does not have the dvantage of microsecond speed elements. Its elements take a millisecond or more to act. e bat's system, therefore, cannot squander its components or its time. Probably it ust often make near-optimum use of many facets of the information it receives. At last e are reaching an effective position for probing into the nature of these mechanisms. hat we find there seems destined to open many doors.

APPENDIX

ULTRASONIC INTERRELATIONS OF BATS AND MOTHS: A DIAGRAMMATIC SUMMARY

INTRODUCTION

Events that shape the pursuit-escape relations of bats and moths have such a long evolutionary history that many complex details of each creature may have been shaped by the survival value of trends in the conflict. Already enough is known to warrant an attempt at systematic representation. Although any such schematized representation oversimplifies, it may also help in visualizing the kinds of forces that shape the general picture. Certainly the bat-moth problem is an unusually intriguing example of evolutionary interaction, containing perhaps, many features beyond those we can now see--or even guess.

Fortunately, a number of the basic elements have been painstakingly investigated and clearly presented by Roeder and Treat, and by other investigators.[2,27-32,34-37] Certain of the broader features of the so-called "bat-moth battle" have also been described. The intention here is to tie together the general form of existing findings rather than to report in detail the quantitative results of individual experiments.

GENERAL FORM OF BAT-MOTH INTERRELATIONS

Figure 39 illustrates in a rough way a possible physical situation where a bat is closely approaching a flying moth. Here the bat is flying more or less toward the moth, while the moth is moving roughly at right angles to the path of the bat. Figure 40 gives a corresponding vector representation. Starting to echo back from the moth is a typical terminal pulse of a Myotis lucifugus. The pulse, shown approximately to scale, is about 1/3 millisecond in duration and sweeps down roughly 8 kc from an initial frequency of 30 kc. Figure 41 gives samples of moth pulses recorded outdoors and illustrates typical changes in the pulses of bats during the initiation of pursuit. Photographs of situations corresponding to Figure 39 have shown that at this juncture the bat might: 1) catch the moth, probably here with the use of the right wing, 2) make an unsuccessful attempt at capture (though commonly with an ensuing successful attempt), or 3) deliberately avoid the moth.* In this latter case, it is unlikely that the buzz-type pulse illustrated would be emitted, since the decision to relinquish pursuit appears to be followed by immediate cessation of such pulses. Examples of actual encounters are given in Figures 42, 43 and 44.

Figure 45 shows very schematically a few potentially significant message paths in bat-moth encounters. The blocks specifying functional categories are intended to give only the crudest idea of the vast array of messages and operations that actually occur,

---

*There are also transitions or combinations as, for example, a catch or hit with apparently deliberate failure to retain. Some of these may be test touches or catches serving to confirm or correct an acoustical evaluation.

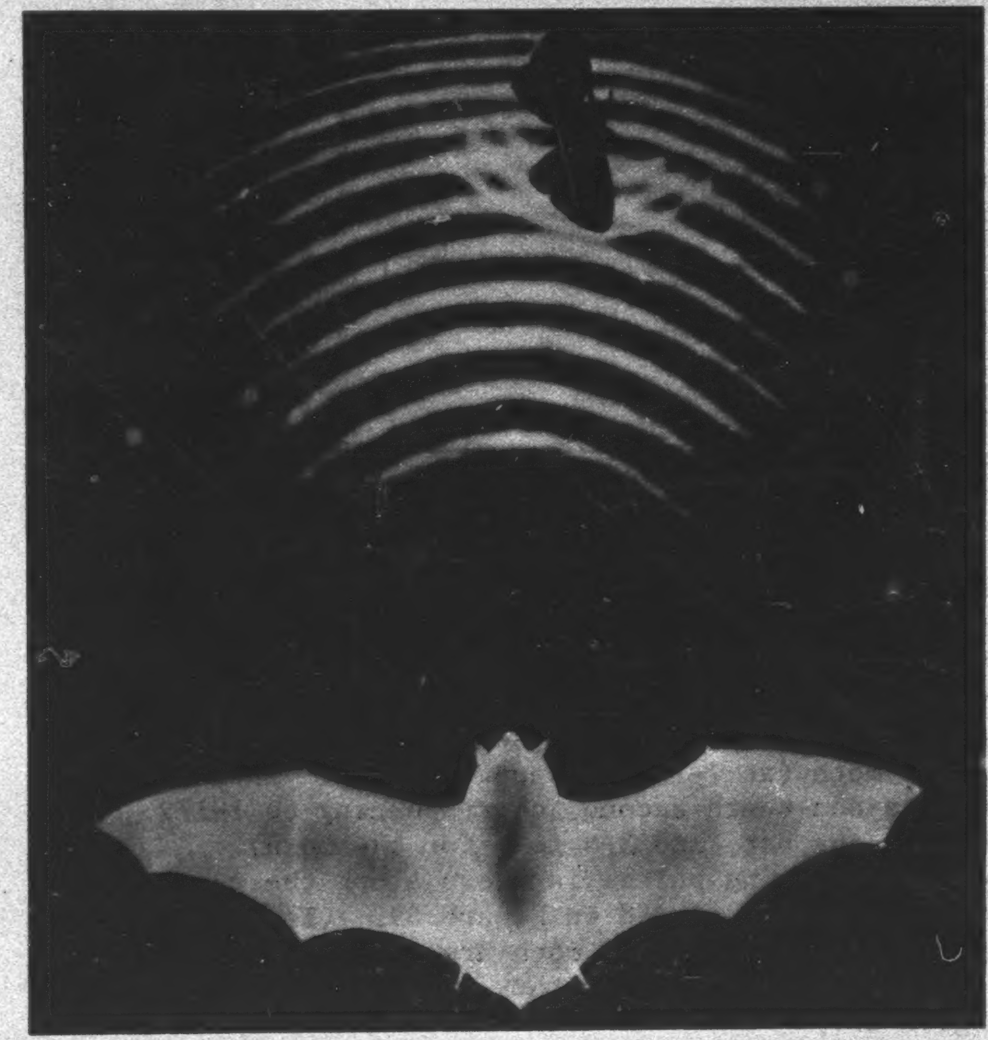


Figure 39. Close Pursuit of a Moth: Physical Situation. The bat, a Myotis lucifugus, is closely approaching a moth (which is flying a course roughly at right angles to the path of the bat). A terminal pulse of approximately one-third millisecond duration is shown, approximately to scale, starting to echo back from the moth. No attempt is made to show the exact energy radiation pattern of the signal. Some energy is actually dispersed in all directions.

and no resemblance to actual anatomical arrangements is intended. The chief feature to note is the complexity of message categories even for the simple situation pictured. The bat must clearly be capable of quick and effective exclusion of detail irrelevant to the immediate pursuit; yet at the same time be capable of meaningful evaluation of the many constraining obstacles and configurations that dictate its flight path.

AUDITORY SYSTEM OF BAT: SURVEY OF POTENTIALLY RELEVANT FEATURES

The general arrangement of a bat's auditory system is shown schematically in Figure 46. Since the system is highly intricate and is discussed extensively by Grinnell[15] only a few brief comments need be made here. Certain features are of special interest, particularly when viewed in contrast to the vastly simpler system of the moth. The following are examples.

1) Extensive frequency and intensity coding occurs peripherally (for example, by way of the hydrodynamic and transduction systems that activate the first order acoustical fibres).

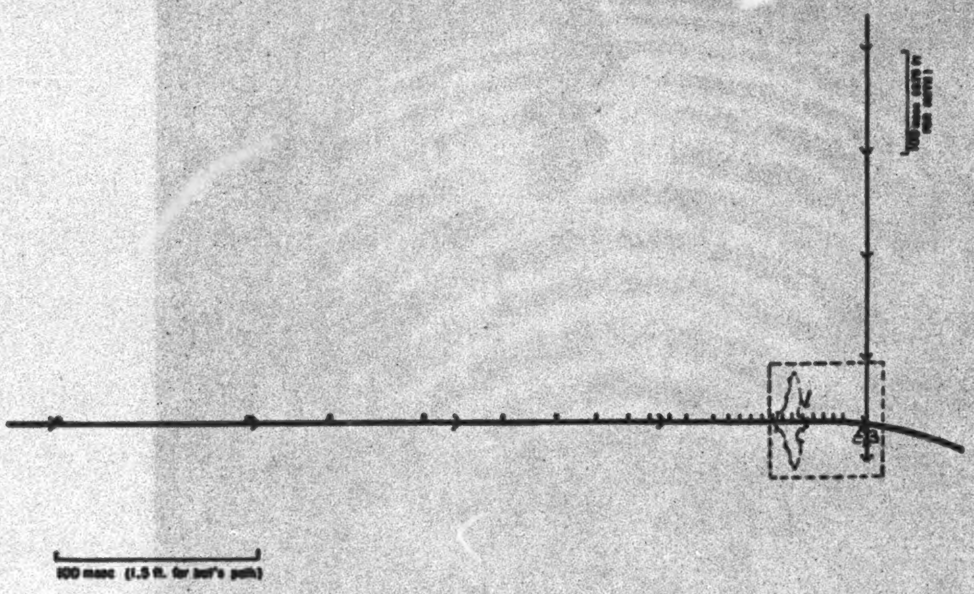


Figure 40. Vector Representation of Figure 39. The horizontal line of arrows indicates the approach path of the bat (at 15 feet per second) while the vertical line of arrows designates the course of the moth (at 7-1/2 feet per second). Each arrow segment represents one-tenth second (corresponding to 1-1/2 feet of travel for the bat, and 3/4 foot for the moth). A typical set of echolocating pulses is shown along the path of the bat. Box shows area included in Figure 39. (In the laboratory, the courses of bat and moth are seldom straight, as indicated here, but out-of-doors they often come closer; see above, Figure 27.)

2) Some rapid time sequence coding may also occur peripherally by way of the outer ear configuration, inner ear hydrodynamics, and transducer coding mechanisms at the point of neural excitation.*

3) Since efferent messages may travel out the auditory nerve as far as the transducing mechanisms, some selective gating or shaping of incoming messages (under central control) may occur as far peripherally as the inner ear. Presensitization also occurs in the auditory centers at certain intervals after pulse emission, suggesting that increased sensitivity may act as a gating mechanism for the reception of echoes at specified times.

4) Interaction between messages from the two ears occurs at several levels and probably by way of a number of different neural mechanisms. Earliest binaural interaction may occur at the large cochlear nuclei, where the first meshwork of auditory synapses is located; but the most extensive low level interaction presumably takes place in the

---

*Relevant here are the experiments of Batteau and collaborators (1) on human auditory localization with the use of high frequency components, partially discussed by Mills.[19] Basic to the relatively direct localizing indications observed with stimulus configurations incorporating sound components above perhaps 7500 cps are: a) a complex sound of adequate bandwidth and b) a multichannel path to the coding mechanisms of the inner ear. The time delays between channels (involving mostly time separations of less than 1/10 millisecond) are presumably coded into a spatial dimension along the basilar membrane and, with brief intervals of correlation, mapped uniquely into external spatial categories. Azimuth, elevation, and approximate range of a discrete source can sometimes be established with remarkable rapidity and accuracy without the use of sequential comparisons or any motion by the head or ear. However, precision and certainty of evaluation are enhanced by the separation of location and quality made possible with more extended correlations and with the use of two ears.

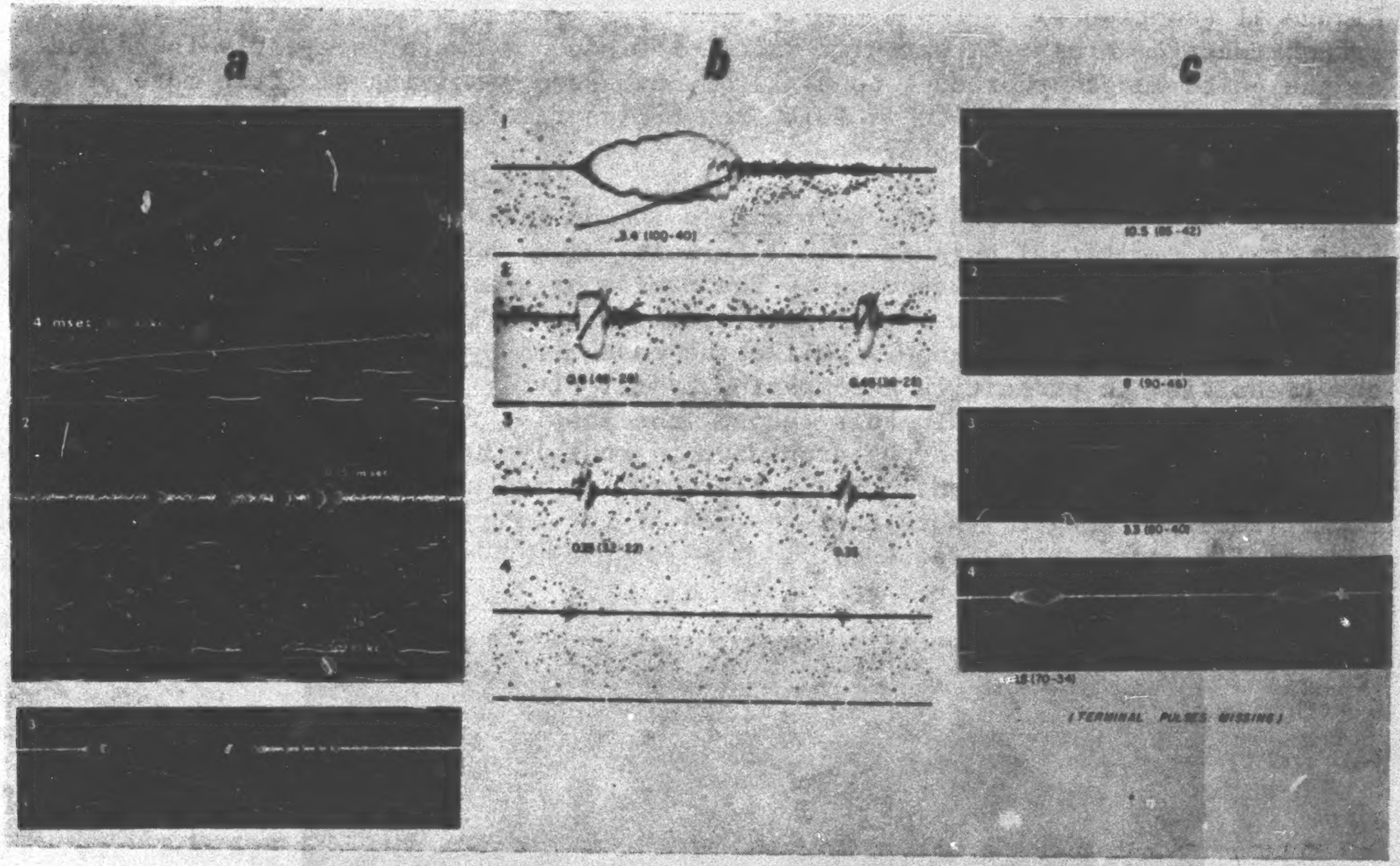


Figure 41. Bat and Moth Pulses. Columns A and C (white on black) were made outdoors at Tyringham, Massachusetts, while Column B was made in the laboratory. Tracing A-1 shows the cruising pulse of an unknown bat, presumably a Myotis, which was circling in the area. Interspersed with some of the pulses of this bat were groups of short pulses--usually five in number--which appeared to be ultrasonic clicks or pulses of an Archtiid moth which was also flying in the area. A typical group is shown in A-2. The output of a meter measuring intervals between the zero crossings of the pulse carrier appears in all tracings. For the bat pulses it shows as a sloping line (or row of dots), the initial lower end of the line representing short zero-crossing intervals (hence, higher frequencies), the terminal upper end of the line representing lower frequencies. The moth pulses have no significant frequency sweep, and the meter output appears as a cluster of dots which correspond, in the present record, to an average frequency of almost exactly 80 kc/sec. The individual pulses of the moth are approximately one-sixth millisecond in duration, the whole group normally occupying about two milliseconds. (Time markings at the bottom of the tracings are either square waves or pulses derived from a 1 kc oscillator.) The smaller scale tracing, A-3, is a simultaneous recording of one of the cruising bat pulses and a group of clicks or pulses from the moth. Several groups of clicks preceeded the one shown here, the moth apparently sending out successive groups of pulses while the bat was near by. No specific time relations were in evidence, however, between the timing of the bat's pulses and the moth's clicks.

Column B illustrates typical changes in pulses form occurring as a Myotis lucifugus executes a successful pursuit. The unparenthesized numbers indicate approximate pulse duration, while the parenthesized figures designate pulse frequency range. The output of the zero-crossing meter forms a relatively straight line for most of the pulses, suggesting a hyperbolic type of frequency drop (since equal ordinate distances represent reciprocals of frequency, 50 kc being 1 cm above 100 kc, 25 kc being 2 cm above 50 kc, and so on). With the pulses of Myotis lucifugus the starting frequency falls markedly during the

Figure 41 (continued).
transition from cruise to pursuit. Rate of frequency sweep is greatly increased as the pulse length shortens, total frequency sweep remaining at first more or less constant, then declining. Pulse repetition frequency during the terminal buzz is 182 pulses per second.

Column C shows pulses of Lasiurus borealis in the field during the transition from cruise to initial pursuit (final pursuit pulses became too weak in this recording for proper reproduction). The cruise or search pulses of a circling red bat usually range from 7 to 11 milliseconds in duration and show some variations of frequency range. Unlike the case with Myotis lucifugus, however, the transition to pursuit is accompanied by relatively little decline in initial pulse frequency. In this record, the initial frequency remained at about 70 kc, in contrast to the drop down to roughly 30 kc often noted in corresponding Myotis records. The pulse duration of Lasiurus also tends to remain somewhat longer. Note that the end of the long cruising pulses is essentially constant in frequency.

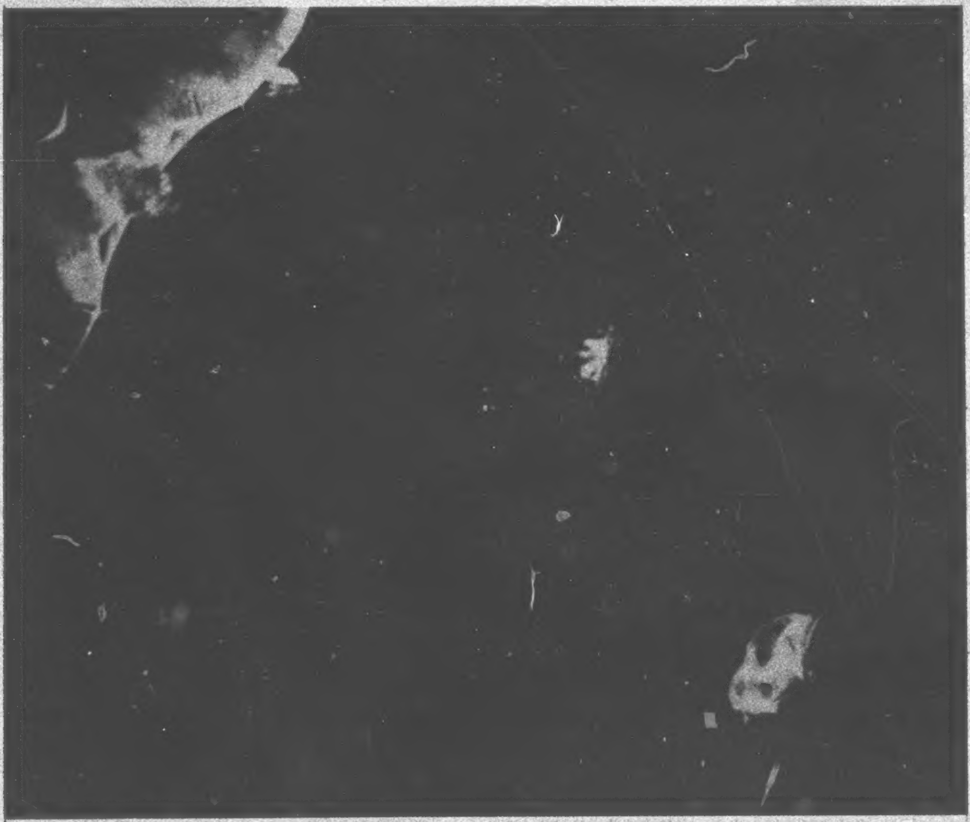


Figure 42. Wing Catch of Moth by Myotis lucifugus. This picture shows an actual encounter not too different at its terminal phase from the hypothetical illustration of Figure 39. Many such pictures were made by catapulting the moth from below as the bat approached. Characteristically, the moth would begin to fly as it reached the peak of the trajectory, sometimes also initiating immediate evasive maneuvers. Use of the wing for such catches or attempts was very common, the proportion of successful catches varying greatly from bat to bat, and according to the violence of the moth's maneuvers. In a few instances, the tips of the moth's wings were clipped before catapulting to reduce the scope of the moth's maneuvers and keep the moth within the photographic field.

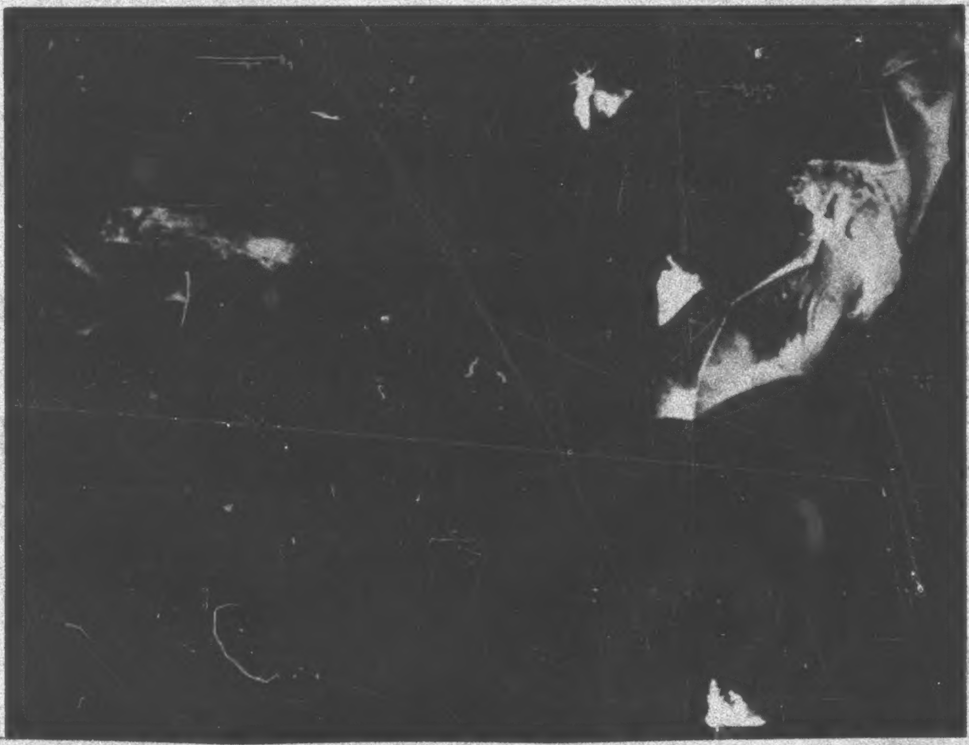


Figure 43. Last-Instant Decision Not to Catch. The final image shows the moth diving down and the bat continuing its flight course.

Figure 44. Catch and Drop of a Moth. The second image shows the bat dropping the moth.

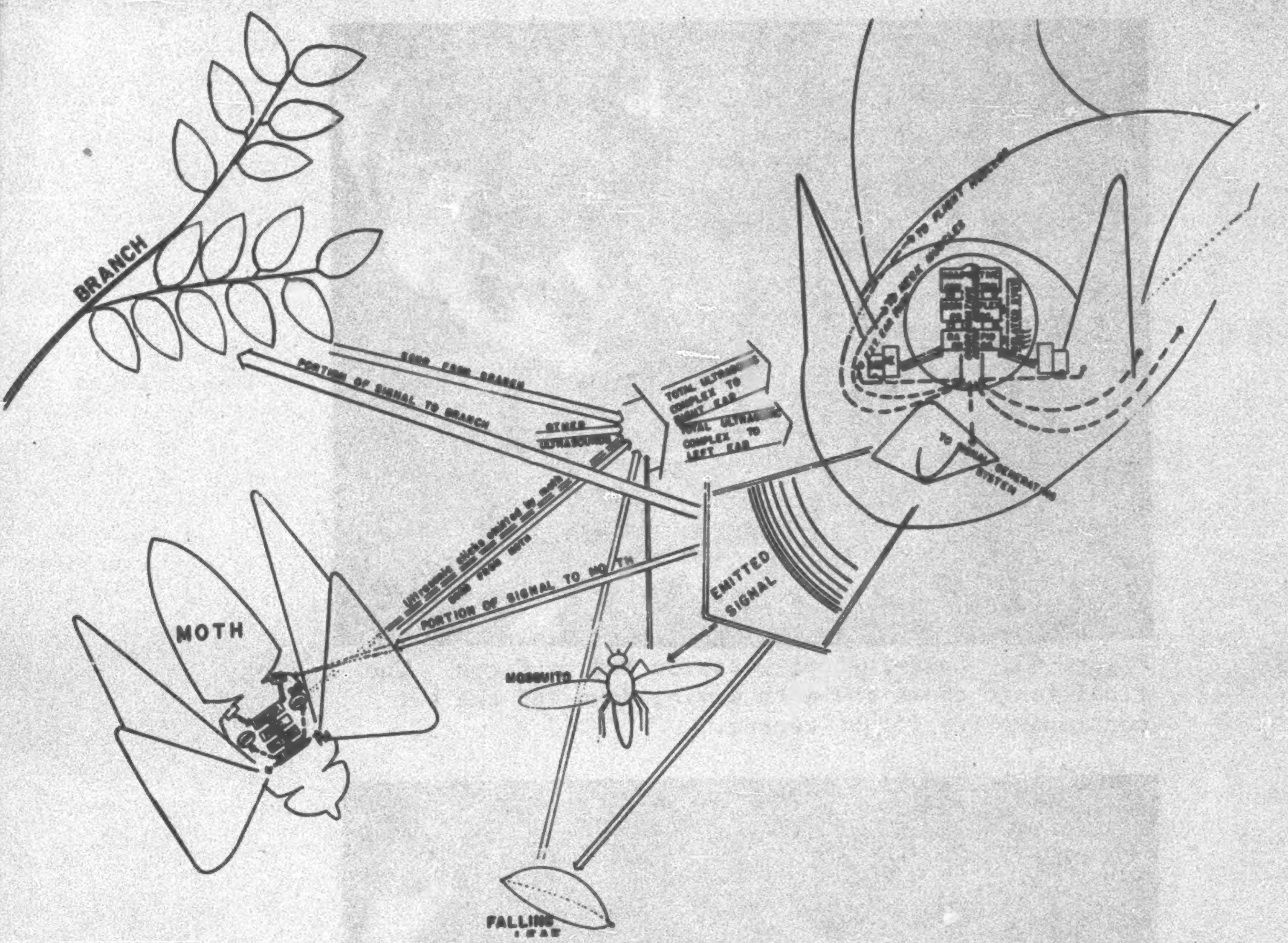

BRANCH
ECHO FROM BRANCH
PORTION OF SIGNAL TO BRANCH
OTHER ULTRASOUNDS
TOTAL ULTRASONIC COMPLEX TO RIGHT EAR
TOTAL ULTRASONIC COMPLEX TO LEFT EAR
TO FLIGHT MUSCLES
TO SIGNAL GENERATING SYSTEM
EMITTED SIGNAL
Ultrasonic clicks emitted by moth
ECHO FROM MOTH
PORTION OF SIGNAL TO MOTH
MOTH
MOSQUITO
FALLING

Figure 45. Some Message Paths in Bat-Moth Encounters. This highly schematic view shows a bat approaching a sound-emitting moth in the presence of various other nearby objects: the foliage of a tree or bush, a falling leaf, and a mosquito (at closer range than the moth). The view is intended merely to suggest some of the kinds of evaluations, discriminations, selections, and resolutions typical of many interception situations. Often only a very small portion of the total ultrasound reaching the bat represents the echo of the desired primary target. To achieve rapid and effective response to the relevant echoes, the bat is presumably able to gate out many more prominant sounds at early processing levels. Efferent pathways to the external ears, the middle ear muscles, and the hair cells of the inner ear (see efferent pathways in Figure 46) may play a role in some of the more peripheral gating, selecting, and correlating devices. These can probably be activated by very rapidly operating mechanisms, as suggested in the diagram of the bat. Rapid adjustments of the emitted signal may also be possible. Related sensory impressions from vestibular, kinaesthetic, and tactile systems must also be integrated into the response mechanisms at various levels. While some responses are presumably set off very quickly on the basis of returns from a single pulse, others such as those to target path or wing action depend on more complex analysis over several pulses. During a given test run in the laboratory a bat also shows a certain amount of adjustment or learning as to the nature of the expected interception situations. The blocks illustrated connote only the broadest of such concepts.

Part of the signal to the moth is shown reflecting back while a small additional portion reaches the moth's tympanic organs (TO). These receptive devices send messages to the sound receptive region of the metathoracic ganglion. Almost nothing is known of what happens in the moth's nervous system beyond

Figure 45 (continued).
the afferent tympanic nerve. Blocks suggesting processing and activating mechanisms are hypothetical. Coordinated motor actions of various sorts are, however, released in response to received ultrasound, notably those governing flight pattern (as suggested by arrows to the flight muscles (FM) and activation of the sound generating tympal organs (SG). Clicks or pulses from these organs obviously reach the bat from the same direction as echoes or the bat pulses returned by reflection from the moth.

olivary complexes at the two sides. Some interaction also occurs in the reticular formation at various levels, but the chief higher level locus of interaction appears to be the posterior colliculus (next main station of the ascending auditory pathway). Grinnell's experiments[15] indicate that, among other actions, what happens at one ear may rapidly alter sensitivity in the other auditory channel.

5) Certain centers, such as the exceptionally prominent nucleus of the lateral lemniscus (also, perhaps, parts of the reticular formation), may have important functions in the selective control of left-right interactions.

6) The posterior colliculus is extremely large and complex and may be the main integrating station for complex incoming messages.

7) Higher stations--notably the medial geniculate and auditory cortex--are small and undeveloped relative to the hyperdevelopment of the cochlear and accessory nuclei and the posterior colliculus. This is presumably in line with the bat's need for extremely rapid analysis and evaluation of received signals.

8) The various centers are close together, favoring rapid conduction.

9) Much neurological structure is very compact, suggesting preset mechanisms of relatively simple routing and restricted processing operations.

10) Various mechanisms, including those of the ear dynamics, seem suited for ultrasonic frequency discrimination.

11) Quick reflex muscular action, probably both of the middle ear and of the outer ear, may act to modify over-all sensitivity--and possibly directional sensitivity--within 10 or 20 milliseconds of stimulus onset or radical change of quality.

12) Various fairly direct motor pathways may lead out at several different levels along the auditory pathways, suggesting that in comparison with many mammals there is greater emphasis on the initiation of early responses to received signals.

A bat's auditory system thus seems specialized for: a) rapid and selective reception of auditory signals, b) appreciation and interpretation of closely-spaced temporal structure and quick evaluation of shifts in the stimulus pattern, c) quick and effective detection of left-right stimulus differences, d) automatic gating for expected relevant stimulus values, e) excellent ultrasonic frequency discrimination, f) fast initial motor responses to external changes as reflected via shifts in echo-pattern. Such features clearly fit it well for the job of rapid evaluation of echo complexes and for a rapid conversion of the indication into appropriate pursuit action.

TYMPANIC SYSTEM OF MOTH

The moth's auditory, or tympanic, system is vastly less complex than that of a bat. Because of its relative simplicity, and because the moth's acoustical evaluations introduce certain basic determinants into many of a bat's more crucial pursuits, a somewhat more specific review of what is known of the moth's system may be in order.

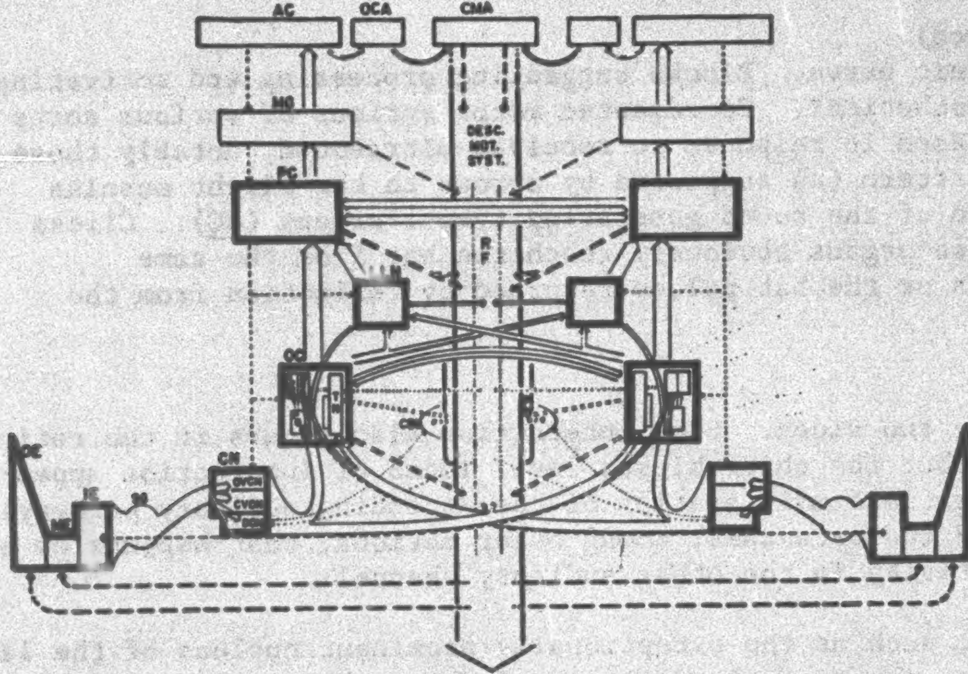


Figure 46. Schematic View of the Auditory System of an Insectivorous Bat. This diagram is intended only as a very general and approximate guide to the kinds of pathways and connections apparently existing in the bat's auditory system. In this crude two-dimensional representation anatomical relations are, of course, grossly distorted. Highly compact and close together, many of the centers are actually so close that they merge--often, apparently, under the influence of "neurobiotaxis" (the growing toward each other of the most functionally related elements). The details shown are drawn almost exclusively from Grinnell.[15] Heavy boxes indicate mechanisms or centers that are strikingly developed in the bat (that is, the microchiroptera, but not the megachiroptera). Relative to other mammals, the most outstandingly developed center in the bat, perhaps, is the nucleus of the lateral lemniscus (LLN). Its exact role is unknown, but presumably it has important governing functions in the rapid processing of auditory inputs and in the manner of their use. Of unusual interest, also, is the medial superior olive (MSO); each of its very large cells apparently receiving inputs from the cochlear nuclei of both sides.

The outer sets of boxes at the two sides represent the peripheral mechanisms respectively of the outer ear (OE), the middle ear (ME), and the inner ear (IE). Passing centrally from the inner ear is the auditory nerve which incorporates the spiral ganglion (where the cell bodies of the first order neurones lie). Three efferent pathways reading out to the peripheral mechanisms are shown: (1) the olivo-cochlear nerve, passing out the auditory nerve, where it apparently has terminations on the hair cells of the basilar membrane, (2) the motor nerve governing the middle ear muscles (Tensor tympani and Stapedius), and (3) the motor nerves specifying the position, action, and configuration of the outer ear.

The auditory nerve splits into three branches which go respectively to the three divisions of the cochlear nucleus: the oral ventral cochlear nucleus (OVCN), the caudal ventral

Figure 46 (continued)
cochlear nucleus (CVCN), and the more separated dorsal cochlear nucleus (DCN). Precisely how the different categories of ascending fibres disperse within the cochlear nuclei is unknown and likewise just how they emerge to form the ascending paths of the central auditory system. Fifty cell types have been identified in the cochlear nuclei. Most fast-conducting fibres appear to cross to the contralateral olivary complex, while, for the most part, fine and more slowly-conducting fibres ascend ipsilaterally. Ipsilateral distribution is multiple: to the pre-olivary nuclei (PON), to the medial superior olive (see above), to the nucleus of the lateral lemniscus, and perhaps elsewhere. Contralateral distribution appears mostly to the trapesoid nucleus (TN)--perhaps also to a small adjacent nucleus (lateral trapesoid nucleus) identified only in certain bats--and to the medial superior olive, mentioned above. The dorsal cochlear nucleus sends a bundle to the vermis of the cerebellum (CBL), and into the dorsal cochlear nucleus comes an efferent nerve of uncertain origin (perhaps from the reticular formation).

Various connections appear to go to and from the so-called "secondary nuclei" (olivary complex and nuclei of the lateral lemniscus--including in some bats an additional dorsal nucleus close to the posterior colliculus). Ascending pathways, presumably with both unilateral and bilateral representations, pass to the lateral lemniscus nuclei of both sides and to the ipsilateral posterior colliculus (PC). Connections are also made with the contralateral olivary complex and with the central nervous systems (notably the pontine nuclei, PN) mediating coordination and equilibrium. Important ascending pathways go from the nucleus of the lateral lemniscus to the ipsilateral posterior colliculus.

The posterior colliculi (PC) in bats, though not showing the greatest hypertrophy relative to other mammals, are the largest nuclei of the auditory system. They receive mostly third- and fourth-order fibres, primarily contralateral, interchange many fibres with the contralateral colliculus, and have numerous connections with the motor system. Presumably they play a very dominant role in the complex auditory analyses that govern oriented behavior.

The higher auditory centers, the medial geniculate (MG) and auditory cortex (AC), are "both absolutely and relatively much smaller than the posterior colliculi."[15, p.26] Ascending pathways, of lesser size than those leading to the colliculi, go to these centers. Connections go to other cortical areas (OCA) and to the motor system (MC = motor cortex). The cortex in bats may play an important role in learning and the various adjustments and variations seen in their responses during tests on interception performance. That bats often take many trials to learn simple things may be related to the very limited cortical capacity of the brain.

The heavy central region represents the descending motor system (desc. mot. sys.). No differentiation into pathways or centers (other than as already mentioned) has been indicated. Broken lines drawn from the ascending centers to the motor system are intended only to show that connections to the motor system exist at various levels--some of these connections presumably being of much importance in the rapid early response typical of a bat's interception behavior.

Figure 46 (continued)
The dotted region in the center represents the brain stem reticular formation (RF). Incorporating connections of many types, this system may serve a number of functions. It relates sensory and motor systems both locally and in more general ways, apparently serving to inhibit or facilitate the transmission of specific messages. In higher forms, it appears to mediate aspects of attentional focus and motivational propensities.

Descending broken lines (drawn at the sides for clarity only) indicate descending central control of the ascending pathways, as discussed in several papers by Galambos. The extent of such pathways and precisely how they operate remains as yet largely unknown.

Experiments by Roeder and Treat[27-32, 34-37*] have provided a useful orientation to the level of analytical complexity and the range of response times that may reasonably be expected of a moth. Their observations, for example, suggest the following.

a) Only the crudest frequency discrimination occurs (which is also consistent with the absence of any linear array of frequency-ordering elements such as typically provides the basis of frequency coding in higher animals).

b) Binaural directional sensitivity is present for lower intensities of a bat's signals, and may act in part to turn the moth away from the bat, thus reducing reflectivity to the bat's signals.

c) Response times are slow compared to those of a bat: mostly 1/5 to 1/2 second (and often longer) for the moth as against about 1/10 to perhaps 1/30 of a second for a bat.

d) The simplicity of the moth's system limits any analysis of the bat's signals to rather few, rough categories (mostly relating, in all probability, to the direction and proximity of the bat). Irregular or random features in the properties of the moth's associated motor responses (perhaps particularly with respect to timing) may, however, greatly complicate the bat's prediction problem.

Figure 47 is a very schematic view of the tympanic system of a typical sound-sensitive moth (as, for example, a noctuid). The sequence of events, upon reception of an acoustical signal, can be outlined roughly as follows. Vibration of the tympanic membrane causes the transducing elements (scolopes) to activate the dendrites (receptor fibrils) of the sensory cells. Relevant aspects of the acoustical signal (as, for example, intensity, duration, and perhaps certain groupings) are coded into the firing pattern of the nerve spikes originating in these two cells. The axons of the cells form the tympanic nerve which transmits nerve impulses to the pterothoracic ganglion in the metathorax of the moth. Very little is known about the neural operations that take place in this ganglion. It is clear, however, that selective and organized motor responses occur as a result of acoustical stimulation. The implication is that appropriate categories of organized motor response can be activated or inhibited in accordance with

---

*A recent paper by Roeder (in Animal Behaviour, Vol. 10, Nos. 3/4 (1962), pp. 300-304) presents further details of the responses of free-flying moths to bat-type signals.

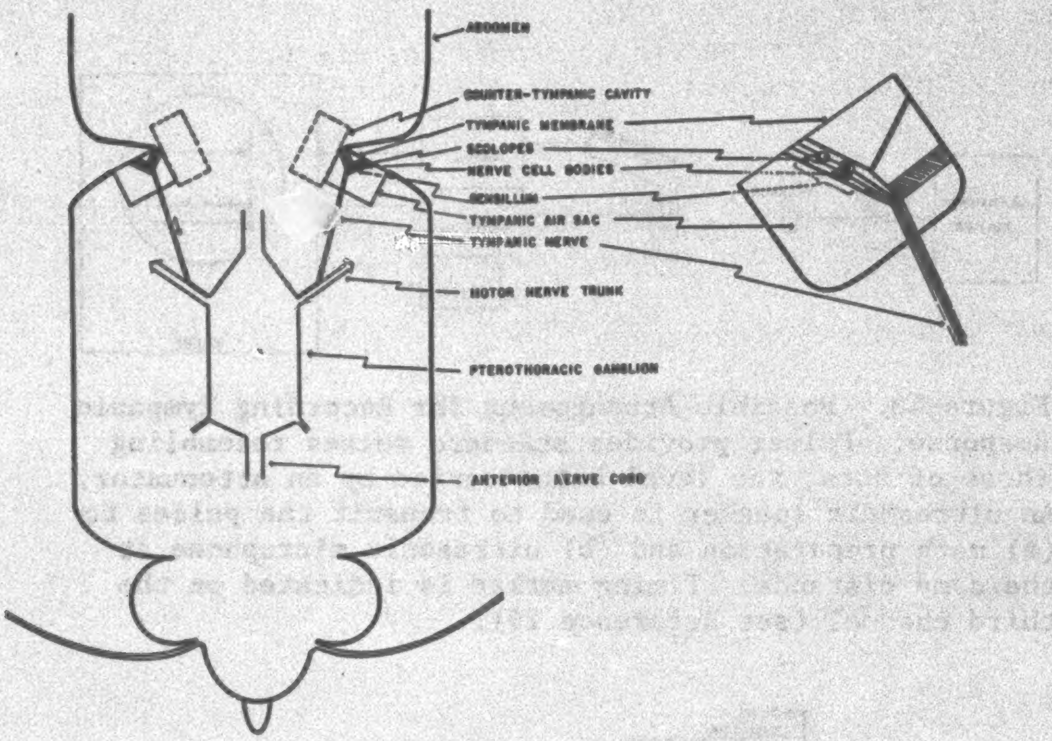


Figure 47. Tympanic System of Noctuid Moth: Schematic Representation. See text for description.

indications derived by way of the tympanic organs at the two sides. Experience and learning presumably play little if any role in shaping the behavior of the moth.

Since the tympanic fibres are accessible for electrical recording, exploration of the incoming nerve impulses in response to acoustical stimulation has been possible. Studies of the responses of intact moths have also been made. The simplest way to review the main observations is in four stages, as follows.

A. Input-output relations for a single tympanic fibre, using as inputs acoustical stimuli of standard form that approximate natural ones;

B. Relations between responses in the two acoustical fibres at one side;

C. Relations between the responses in the pairs of acoustical fibres at the two sides; and

D. Samples of responses of intact moths to acoustical stimuli. Fortunately the known relations are relatively simple and can readily be summarized in graphic form.

SOME INPUT-OUTPUT RELATIONS FOR A SINGLE TYMPANIC FIBRE

Figures 48, 49 and 50 illustrate in schematic form a possible recording arrangement and give samples of stimulus-response situations. If we assume a standard ultrasonic pulse of fixed duration (say 2 milliseconds) but of variable level or intensity, then the main response shifts that occur with changes of signal level may be defined in terms of: 1) latency in the appearance of spikes, 2) duration of the spike group, 3) total number of spikes, and 4) initial rate of spike discharge. In the end, of course, other stimulus parameters than level or intensity must be evaluated. Stimulus configurations that are obviously related to important natural situations might, for example, include: high signal rates, multiple echoes, and complex echo patterns of the type reflected from trees. It is thus necessary to consider such response variables as: accommodation effects, multiple response levels and groupings, response irregularities, etc. Level of excitation for a given stimulus unit also varies according to surrounding conditions, and decays more or less exponentially in the absence of significant stimuli. The most notable feature of the response of a given fibre, in relation to stimulus intensity as

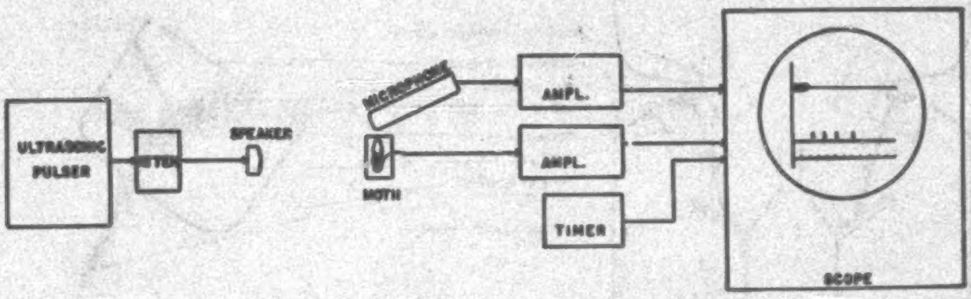


Figure 48. Possible Arrangement for Recording Tympanic Response. Pulser provides standard pulses resembling those of bats, the level being varied by an attenuator. An ultrasonic speaker is used to transmit the pulses to (a) moth preparation and (b) ultrasonic microphone at the same distance. Timing marker is indicated on the third channel (see Reference 29).

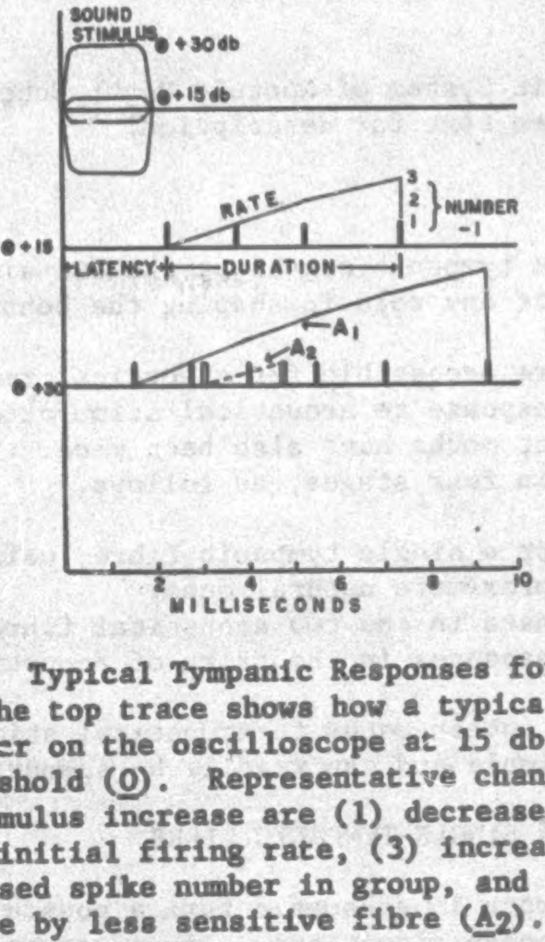


Figure 49. Typical Tympanic Responses for Two Stimulus Levels. The top trace shows how a typical pulse envelope might appear on the oscilloscope at 15 db and at 30 db above threshold (O). Representative changes seen with such a stimulus increase are (1) decreased latency, (2) increased initial firing rate, (3) increased duration, (4) increased spike number in group, and (5) beginning of response by less sensitive fibre (A_2). Since isolated spikes probably do not, on the average, produce significant excitation, spike number is more meaningfully and conveniently represented as one less than the total number in the group.

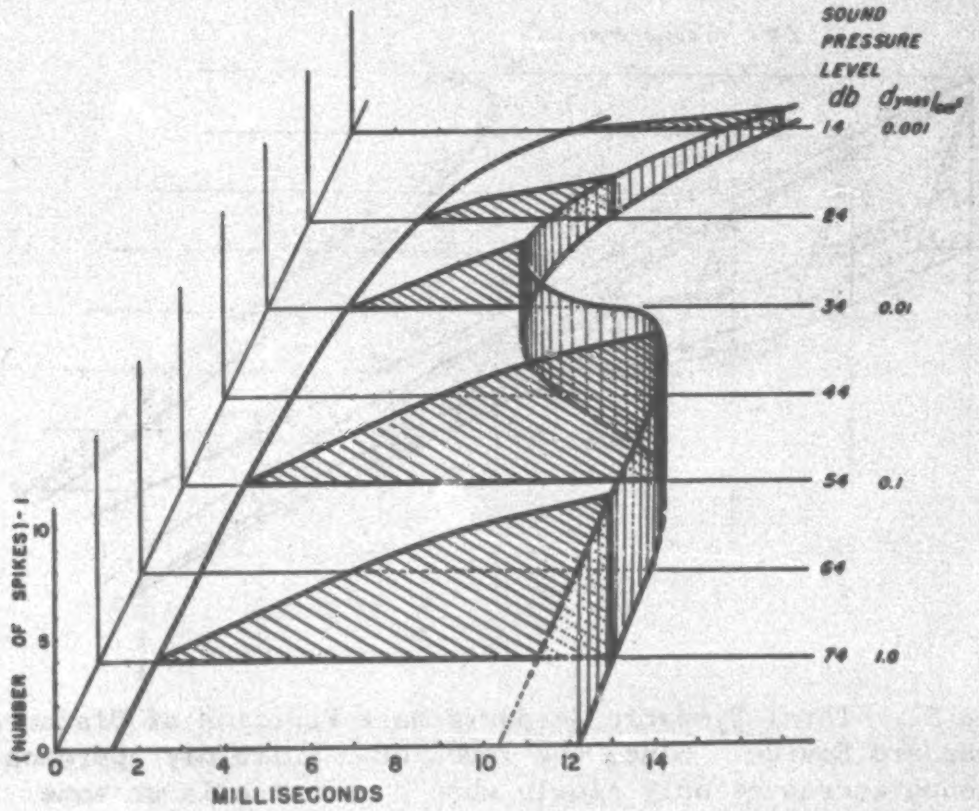


Figure 50. Changes in Response by One Fibre to Increasing Signal Level. The shifts illustrated here are perhaps slightly exaggerated to emphasize the trends. Near the threshold the chief changes are decreased latency and increased firing rate. Though group number tends to increase with increased firing rate, some records show a decrease in duration of group, which holds down the total number. Further increase in signal level (from perhaps 20 db to 35 db above threshold) often produces large increases in duration and number, with saturation occurring at about 40 db above threshold. The effective response zone of a given fibre thus tends to run over less than 40 db of signal level increase.

such, is certainly the tendency of large response changes to be concentrated in the region relatively close to threshold excitation.

SOME INPUT-OUTPUT RELATIONS FOR THE TWO FIBRES AT ONE SIDE

Figures 48, 49 and 50 illustrate response changes noted in a given sensitive tympanic fibre (A1) as the pressure level of a standard stimulus was increased by constant decibel increments. They also show the initiation of firing by the less sensitive fibre (A2). Evaluation of a moth's actual responses to an approaching bat, however, is more readily visualized in terms of equal increments of distance of the stimulus source. This situation is summarized in Figure 51 for the four tympanic fibres (two at the near side and two at the far side--assuming the moth to be flying across in front of the bat). As in Figures 48, 49 and 50 the response is shown in terms of "excitation triangles," where the height of the triangle is one less than the number of spikes in the group, and the length of the base designates duration. Though the illustration assumes a brief stimulus pulse of constant length and frequency composition, this idealization probably would not result in response trends by the moth very significantly different from those shown.

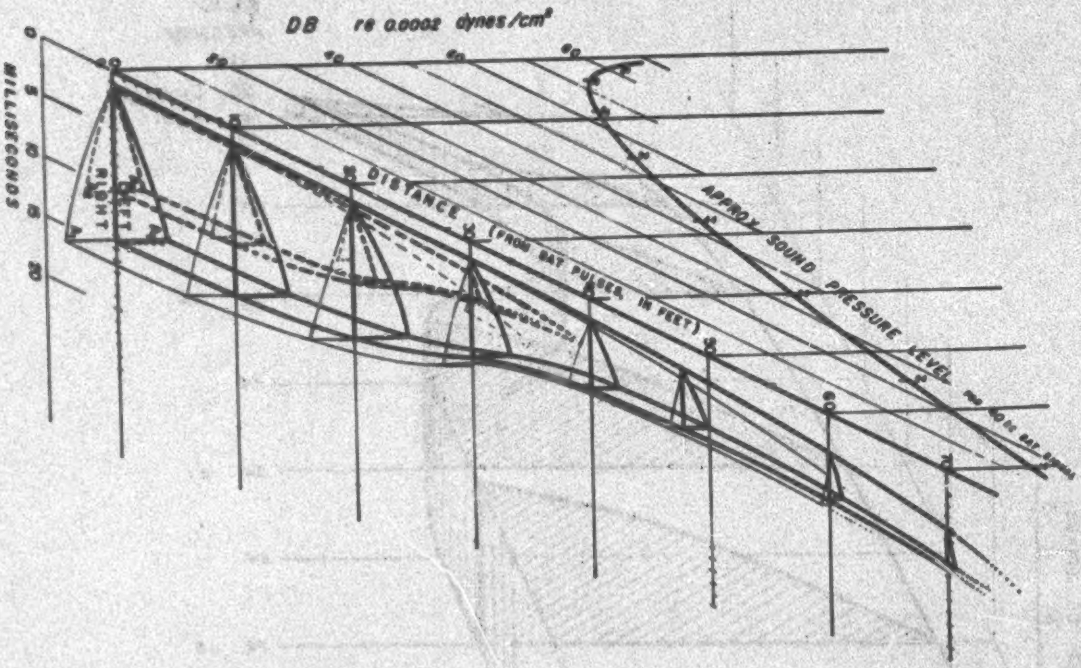


Figure 51. Total Tympanic Response as a Function of Distance to Standard Source. Since the level of a uniformly approaching sound increases only slowly when the source is at some distance (see sound pressure curve), the threshold response changes, which seem rapid in the representation of Figure 50, now appear much more gradual. The response trends of the more sensitive fibres ($\underline{A}_1$) are indicated in solid lines (left, above reference axes; right, below), while the trends of the less sensitive fibres ($\underline{A}_2$) are indicated with broken lines (some connecting lines being omitted for clarity). For the values used in the present illustration, it is clear that the most striking shifts occur as the source approaches from a distance of about 40 feet to a distance of about 20 feet. Note, however, that the moth's motor response(s) might not occur for a half-second or more after this, during which time a red bat may approach 15 feet closer.

The response trends for the two fibres at the near (left) side are shown by the triangles above the reference axes, while the response trends for the two fibres at the far (right) side are indicated by the triangles below. Solid lines are used for the more sensitive ($\underline{A}_1$) fibres and broken lines for the less sensitive ($\underline{A}_2$) fibres. If one compares the response trends, in the two near-side (left) fibres, as a function of the distance of the source, it is clear that the second fibre would be firing only over about half the total range to which the first fibres would be responding. Moreover, the build-up of excitation in the second fibre would be much faster. As indicated earlier, saturation would occur in both fibres while the bat was still at some distance.

The sound pressure line of Figure 51 is given for one frequency, 40 kc, corresponding to an attenuation rate by the atmosphere of roughly one-third to one-quarter of a decibel per foot. The increasing rate of attenuation with higher frequencies is illustrated in Figures 52, 53 and 54 and tabulated in Table 10 of Reference 8. A large portion of the energy in the signals of Eptesicus (used in response distance studies by Roeder and Treat) lies in the 20 to 40 kc region, while the energy in the signals of Lasiurus and Myotis (except for the buzz of Myotis) is mostly concentrated from 40 kc to perhaps 80 or 90 kc. The present value is thus intermediate between the several bats. The absolute level of the sound pressure line is anchored by the levels of typical bat pulses as given, for example, by Griffin.[8] It is still necessary, however, to decide

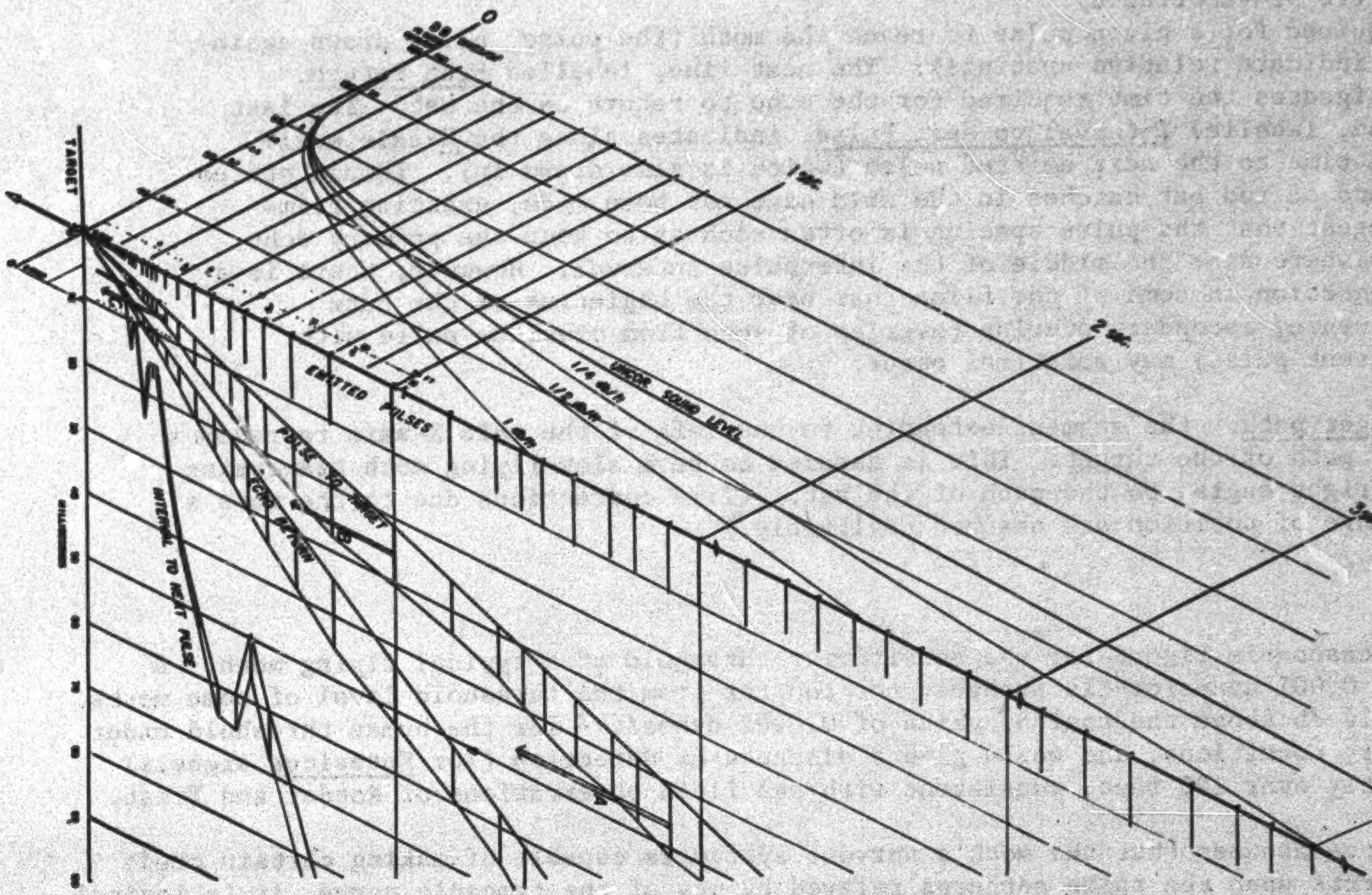


Figure 52. Bat-Moth Encounter: General Quantitative View.

__Z-axis__: The approach path of the bat is indicated by the heavy line, which also represents the __Z__-axis. Flight speed is assumed constant at 24 feet per second, seconds from interception being indicated by vertical (__Y__-axis) lines. A representation of the bat itself, approximately to scale, is given close to each time line. Pulse sequences of the sort obtained in various recordings of red bats in the wild are shown along the upper side of the flight line, the pulses appearing as small spikes. These pulses also appear in expanded representation, off to the right along the __X__-axis direction.

__Y-axis__: The __Y__-axis specifies the sound pressure level reaching the moth as a function of the distance of the bat. The line labelled __Uncor. sound level__ follows the theoretical inverse square function with no allowance for atmospheric attenuation. The three lines below the uncorrected line indicate, respectively, the approximate attenuation functions for rates of 1/4 db/ft (25-30 kc); 1/2 db/ft (35-40 kc); and 1 db/ft (85-95 kc). The exact rates of attenuation vary with conditions (e.g., temperature and humidity). For a given signal intensity, bats that distribute most of the energy in the high frequency range (e.g., __Lasiurus__) might thus not be detected until they were within 50 feet, while bats using lower frequencies (e.g., __Eptesicus__) might be detected at over 100 feet.

__X-axis__: Essentially, the __X__-dimension is used for expansion of sections of the __Z__-axis to a scale that permits more detailed observation of the time relations in the interpulse intervals. The set of heavy lines extending out from the __Z__-axis represent the pulses being emitted by the bat. They are shown varying in duration from 7 to 11 msec, and in spacing (except after detection of the target) from about 70 to 200 msec. The first line to the right of the bat's flight line is labelled __Pulse to Target__ and gives the time

Figure 52 (continued).
required for a given pulse to reach the moth (the pulse being drawn again to indicate relative spacings). The next line, labelled Echo Return, designates the time required for the echo to return to the bat. The last line, labelled Interval to Next Pulse, indicates along the X-axis scale the time to the next emitted pulse (which is also drawn in). Though stereo sound of red bat catches in the wild have not been made, existing films suggest that the pulse spacing is often such as to keep the primary echo somewhere near the middle of the interpulse interval. However, there is a suggestion in some of the films that near the beginning of the buzz sequence, secondary overlap (overlap of echo from previous pulse with present pulse) may sometimes occur.

Target path: the segment extending to the left of the main X-axis represents the path of the target. This is assumed to be a slow-flying moth traversing at right angles to the path of the bat. (Time corrections due to the moth's change of position are assumed negligible.)

upon a reasonable figure for the sensitivity threshold of a typical flying moth. A value of 0.001 dynes/cm^2 is probably not too far from the threshold level of some moths. This is 14 db above the nominal value of 0.0002 dynes/cm^2 for the human threshold under laboratory conditions, and would give a distance of detection (for Eptesicus signals) of slightly over 100 feet, consistent with the field observations of Roeder and Treat.

If one assumes that the moth's nervous system is capable of making certain crude measurements upon the spike patterns relayed by way of the tympanic nerve, it is logical to ask about the kinds of measures that might be most profitable. Significant intensity levels or shifts of level might, for example, be given by such measures as: 1) the firing rates of one fibre, 2) the difference or ratio between A_1 and A_2 firings, 3) the difference in latencies, or 4) group numbers. Other kinds of measures might relate to differences between the early part of a group and a later part. For example, the response of a moth's system to direct and echoing signals is shown in Figure 6B of Reference 30. Even though the portion of a bat's signal received directly might produce saturation, portions reflecting off nearby objects, or the ground, might provide usable indications as to the distance (and possibly direction) of the object or surface. Other groupings of significance might be related to the phase of pursuit of a nearby bat (see, for example, Figures 4 and 5 of Reference 31). Here, the appropriate measures might act to trigger specific evasive tactics or to set off (or shift in character) moth-emitted pulses which act to cause cessation of the bat's pursuit.

RELATIONS BETWEEN TYMPANIC SPIKE PATTERNS AT THE TWO SIDES

It is generally assumed that bilaterality in sense organs is chiefly related to: a) directional determinations, b) range determinations, c) evaluation of motion, and d) reliability, speed, and precision of spatial evaluations in general. For the sound-sensitive moth, the main contribution of the bilateral receiving systems appears to be directional evaluation in terms of azimuth. The lighter lines below the reference axes in Figure 51 represent the response of the fibres at the far side. (Some connecting lines have been omitted for clarity.) The trends shown are at best only very approximate but give some idea of the kinds of differences that may occur between near and far sides. The most obvious difference perhaps is the increased latency near threshold for each type of fibre. Firing rate and group number may also be significantly different at the two sides at low levels of the signal; but high signal levels appear to abolish differential directional indications.

Examples of left-right differences in the response to red bats flying outdoors are given in Figure 7 of Reference 30. Concerning the observed relations the authors advance the following interpretation:

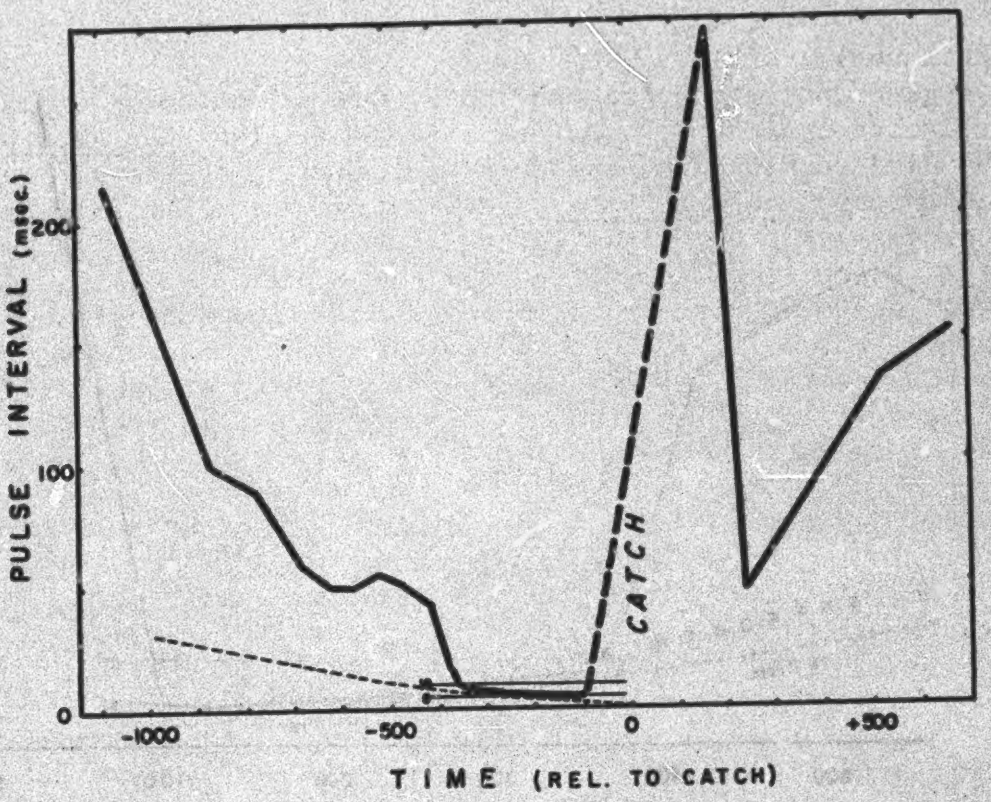


Figure 53. Bat-Moth Encounter: Catch of Catapulted Target by Wild Red Bat--Pulse Repetition Pattern. The heavy line shows the intervals between pulses, as noted previously for laboratory catches in Figures 35 and 36. Unfortunately controlled distance measurements were not made with this sound-on-film record, and consequently the exact distance of the bat from the target could not be determined. The fine broken line indicates estimated echo time for the apparent path of approach. In this record the pulse interval pattern appears to be divided into several rather distinct portions: (1) a rapid increase in rate, starting about one second or 15 to 20 feet away from the eventual catch; (2) a plateau of about 50 millisecond space which occurs about a half-second from the catch; (3) another sudden increase in rate just before one-third second from the catch; (4) a tenth-second transition zone into the final buzz; (5) the terminal buzz; and (6) a silent interval of about a tenth-second just before the catch. (After the catch there is the usual long pause while the target is being grasped.) See next figure for details.

> "If it is assumed that the bat is first detected at 100 feet and approaches on a straight path at right angles to the moth's course...the differential tympanic nerve response would diminish throughout the approach and disappear completely when the bat was 15 to 20 feet away."p.144

The moth's ears are also individually sensitive to the direction of ultrasound (Reference 32, Figure 6); and hence a moth with only one functioning tympanic system (as often occurs with invasion by mites) may gain at least primitive directional indications.

RELATIONS INVOLVING THE RESPONSE OF INTACT MOTHS TO BAT-TYPE SOUNDS

The value of directional data to the moth, as already mentioned, may be primarily that it enables the moth to turn away from the bat, thus greatly reducing its own reflectivity. No reliable estimates currently exist as to how far away a bat can detect

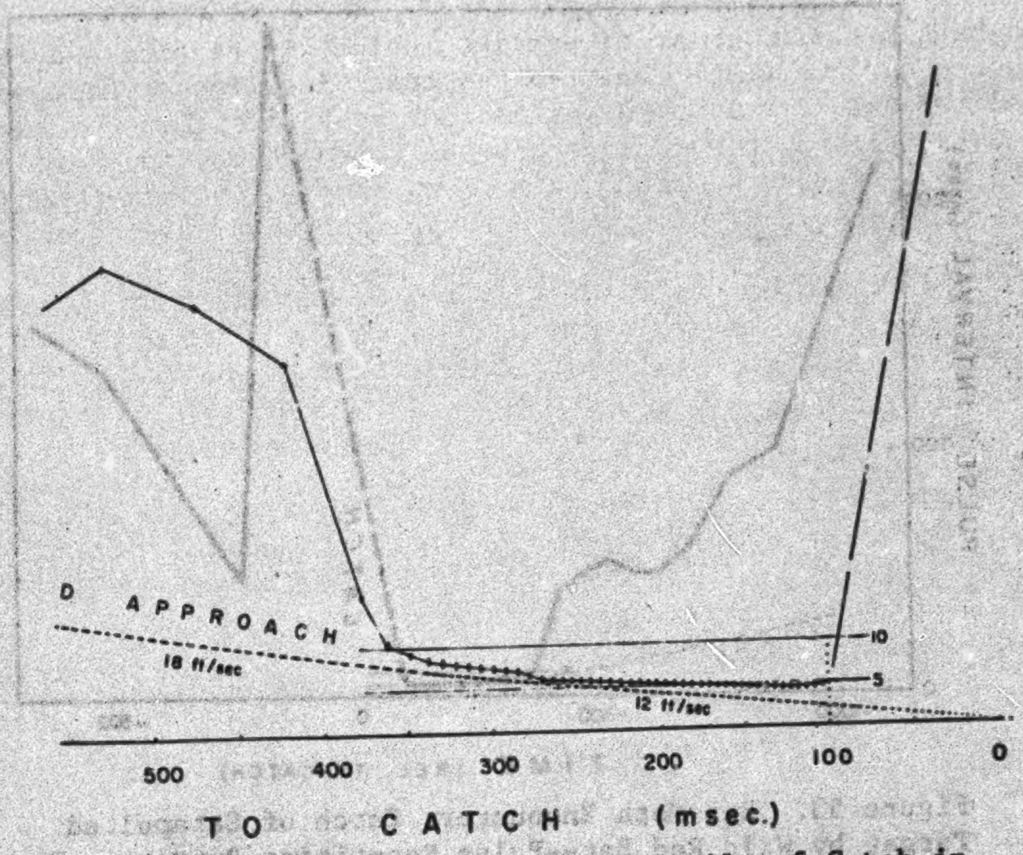


Figure 54. Bat-Moth Encounter: Buzz Details of Catch in Figure 53. There is a strong suggestion in this and other records made in the wild that the pulse spacing near the transition zone into the buzz approximates fairly closely the echo time to the target. In contrast to the constant buzz spacing typical of Myotis lucifugus, this record does indeed show a progressive increase in rate, but with a sudden small jump in rate just as the uniformly increasing terminal portion starts. Records like these raise the question of whether the bat deliberately adjusts the spacing to approximate some desired relation between a given echo and the next emitted pulse while making use, possibly, of partial secondary overlap. Note that since the pulse rate is increasing, the sequence of echoes would tend to arrive at a slightly slower rate than the emitted sequence (since they are displaced one interval back). It is conceivable that out of such an arrangement the bat could make some type of vernier measurement of range.

an average flying moth. Common guesses range over a factor of 10, i.e., from 5 to 50 feet (about 1-1/2 to 15 M). Two things are certain, however: 1) that a moth can normally hear an approaching bat before the bat can detect echoes from the moth, and 2) a moth flying with its axis parallel to the direction of the bat cannot be detected nearly as far away as one that is flying crosswise. Since it is doubtful that a moth has any memory of a bat's direction, and since the moth's system appears to saturate (and abolish directional sensitivity) when a bat (other than a soft-signalled bat like Plecotus) comes near, the moth is presumably incapable of directional responses as the bat attacks. The frequent propensity of moths to dive or spiral downward upon the close approach of a bat suggests that reference to gravity may be the predominant directional influence when bats are close at hand. Current evidence certainly tends to support the hypothesis that directional response occurs when a bat is at some distance, typically prior to a bat's detection of the moth.

Various features of the responses of intact moths to audible and ultrasonic frequencies have been tested,[34,35,30,27] including: initiation and cessation of flight, change in wingbeat pattern, onset of evasive action, initiation and cessation of click generation, and other actions. Measured response times ranged for the most part between about 1/12 and 1/3 sec, (even up to one second) response times for typical night temperatures being rather longer than response times at daytime temperatures. High intensities of sound produced much quicker responses, with less temporal variability, than did low intensities. By directing bat-type pulses at flying moths, Roeder observed:

> "Moths turned away from the sound source when they were at some distance or the sound intensity was low. Flight on a relatively straight path was noted in an upward, lateral, or downward direction, depending on the position of the moth relative to the sound when the ultrasonic pulse train was initiated." 27, p.56

In contradistinction to these "directional maneuvers," "non-directional maneuvers" were noted at higher intensities, including:

> "passive fall with folded wings, a power dive, an alternation of passive fall and power dive, sharp turns and loops followed by passive fall or power dive, a continuous series of tight turns, and other complex maneuvers." 27, pp.56-57

In a very limited set of sample tests, conducted with the help of T.F. Gregg, moths were tethered to the ceiling of the bat flight room by use of long fine wires (0.001 inches or 0.002 inches diameter) while bats made attempts to capture them. The tethered moths initiated many of the maneuvers described by Roeder, sometimes as a function of the bat's distance or phase of pursuit but sometimes, apparently, in some relation to the duration or constancy of a bat's close range activity, suggesting some stored representation of the bat's nearby presence.

From tests such as those mentioned in this section there is certainly evidence that moths are incapable of the quickly initiated and accurately directed responses so typical of the bat. The moth, for its escape, appears to depend heavily upon: 1) unpredictability in the specific timing and direction of its maneuvers, 2) sharp turning radius at appreciable flight speeds (perhaps often 5 to 10 feet per second), 3) loops or spirals which may tend to cause hunting in the bat's predictive procedure, and 4) diving for protective areas, such as the grass. The moth cannot outfly the bat, nor escape reliably by any readily predicted tactic.

QUANTITATIVE SURVEY OF BAT-MOTH ENCOUNTER

The final step in this brief and rough review of the ultrasonic interrelations of bats and moths is to summarize diagrammatically some of the main features of a representative pursuit situation. Figure 52 gives a rather generalized and idealized quantitative view of such an encounter. The bat (Lasiurus borealis) is shown approaching uniformly along the Z-axis, while the moth is traversing slowly along the direction of the X-axis. The sequence of X-axes that go out from the points of pulse emission by the bat, however, represent separate expansions of the Z-axis--showing, toward the end of the pursuit, the relevant time relations of pulses and echoes. The Y-axis is used for the designation of magnitude (in this plot, of sound level). The three dotted arrows (A, B and C) indicate possible response times, for a typical moth, to different phases of the bat's pursuit. Figures 53 and 54 show final pursuit in greater detail.

As indicated earlier, the moth's specific evaluations of the bat's position tend to deteriorate and perhaps disappear as the bat approaches, whereas just the reverse is true of the bat. The bat's reliability of detection, and its speed and precision of interception, increase markedly as it gets close to its target. There is thus an enormous discrepancy between the region of maximal acoustical effectiveness of the part of the moth as compared with that of the bat. Logically, the moth's advantage would thus seem to lie in its capacity to prepare for, and perhaps forestall, the close approach of the bat. Yet moths keep flying, even in the presence of many circling bats. Often they appear to rely, for escape, upon some last-instant tactic, suggesting that certain triggering mechanisms may act under relatively high levels of the bat's signals. A few moths appear to have evolved a special bag of tricks: the production of ultrasonic pulses themselves. How these pulses act upon the different kinds of bats, and what they may signify in terms of warning, deception, or confusion remains to be discovered. Present evidence clearly suggests that they may often be very effective. Undoubtedly many aspects of this intricate game between pursuer and pursued remain to be discovered; and surely the true significance of the many patterns in the existing picture may take a very long time to unravel.

REFERENCES

1. Batteau, D.W. *The Mechanism of Human Localization of Sounds with Application in Remote Environments*. Naval Ordnance Test Station, Contract No. 125-(60530)-27872A, 1962.
2. Blest, A.D., Collett, T.S., and Pye, J.D., "The Generation of Ultrasonic Signals by a New World Arctiid Moth," *Proc. Roy. Soc*. (in press).
3. Galambos, R., "The Avoidance of Obstacles by Flying Bats," *ISIS*, Vol. 4, No. 11 (November 1959).
4. Galambos, R., and Griffin, D.R., "Obstacle Avoidance by Flying Bats: The Cries of Bats," *J. Exp. Zool*., Vol. 89 (1942), pp. 475-490.
5. Gould, E., "The Feeding Efficiency of Insectivorous Bats," *J. Mammal*., Vol. 36 (1955), pp. 399-407.
6. Gould, E., "Further Studies on the Feeding Efficiency of Bats," *J. Mammal*., Vol. 40 (1959), pp. 149-150.
7. Griffin, D.R., "Bat Sounds Under Natural Conditions with Evidence for the Echolocation of Flying Prey," *J. Exp. Zool*., Vol. 123 (1958), pp. 435-466.
8. Griffin, D.R. *Listening in the Dark*. New Haven, Connecticut: Yale University Press, 1958.
9. Griffin, D.R., Dunning, D., Cahlander, D.A., and Webster, F.A., "Correlated Orientation Sounds and Ear Movements of Horseshoe Bats," *Nature* (in press).
10. Griffin, D.R., and Galambos, R., "The Sensory Basis of Obstacle Avoidance in Flying Bats," *J. Exp. Zool*., Vol. 86 (1941), pp. 481-506.
11. Griffin, D.R., and Grinnell, A.D., "Ability of Bats to Discriminate Echoes from Louder Noise," *Science*, Vol. 128 (1958), pp. 145-147.
12. Griffin, D.R., McCue, J.J.G., and Grinnell, A.D., "The Resistance of Bats to Jamming," (paper in preparation).
13. Griffin, D.R., and Novick, A., "Acoustic Orientation in Neotropical Bats," *J. Exp. Zool*., Vol. 130 (1955), pp. 251-300.
14. Griffin, D.R., Webster, F.A., and Michael, C.R., "The Echolocation of Flying Insects by Bats," *Anim. Behav*., Vol. 8 (1960), pp. 141-154.
15. Grinnell, A.D. *Neurophysiological Correlates of Echolocation in Bats*. ONR Technical Report No. 30 (NR-301-219), June 1962.
16. Grinnell, A.D., and Griffin, D.R., "The Sensitivity of Echolocation," *Biol. Bull*., Vol. 114 (1958), pp. 10-22.
17. Kay, L., "A Plausible Explanation of the Bat's Echolocation Acuity," *Anim. Behav*., Vol. 10 (1962), pp. 34-41.
18. McCue, J.J.G., "How Bats Hunt with Sound," *Nat. Geographic*, Vol. 119 (1961), pp. 570-578.
19. Mills, A.W., "Auditory Perception of Spatial Relations," in L.L. Clark (ed.) *Proceedings of the International Congress on Technology and Blindness, Vol. II*. New York: American Foundation for the Blind, 1963.
20. Novick, A., "Orientation in Paleotropical Bats," *J. Exp. Zool*., Vol. 138 (1958), pp. 81-154.

21. Payne, R. *Acoustic Orientation of Prey by the Barn Owl, Tyto alba*. ONR Technical Report No. 1 (NR-301-549), November 1961.

22. Pye, J.D., "A Theory of Echolocation by Bats," *J. Laryng. Otol.*, Vol. 74 (1960), pp. 718-729.

23. Pye, J.D., "Echolocation by Bats," *Endeavour*, Vol. 20 (1961), pp. 101-111.

24. Pye, J.D., "Perception of Distance in Animal Echolocation," *Nature*, Vol. 190 (1961), pp. 362-363.

25. Pye, J.D., Flinn, M., and Pye, A., "Correlated Orientation Sounds and Ear Movements of Horseshoe Bats 2," *Nature* (in press).

26. "Vespertillio," in A. Rees (ed.) *Rees's Cyclopaedia*, Vol. 37. London: Longman, Hurst, Rees, Orme, and Brown, 1819, p. 22.

27. Roeder, K.D., "Ultrasonic Interaction of Bats and Moths," in E.E. Barnard and M.R. Kare (eds.) *Biological Prototypes and Synthetic Systems*. New York: Plenum Press, 1962.

28. Roeder, K.D. *Nerve Cells and Insect Behavior*. Cambridge: Harvard University Press, 1963.

29. Roeder, K.D., and Treat, A.E., "Ultrasonic Reception by the Tympanic Organ of Noctuid Moths," *J. Exp. Zool.*, Vol. 134 (1957), pp. 127-158.

30. Roeder, K.D., and Treat, A.E., "The Detection and Evasion of Bats by Moths," *Amer. Scientist*, Vol. 49 (1961), pp. 135-148.

31. Roeder, K.D., and Treat, A.E., "The Detection of Bat Cries by Moths," in W. Rosenblith (ed.) *Sensory Communication*. Cambridge: MIT Technology Press, 1961.

32. Roeder, K.D., and Treat, A.E., "The Acoustic Detection of Bats by Moths," *Proceedings of the 11th Entomological Congress* (in press).

33. Schneider, H., and Mohres, F.P., "Die Ohrbewegungen der Hefeisenfledermause (Chiroptera, Rhinolophidae) under Mechanisms des Blidhorens," *Z.f. Vergl. Physiol*, Vol. 44 (1960), pp. 1-40.

34. Treat, A.E., "Response to Sound in Certain Lepidoptera," *Ann. Entomol. Soc. Amer.*, Vol. 48 (1955), pp. 272-284.

35. Treat, A.E., "The Reaction Time of Noctuid Moths to Ultrasonic Stimulation," *J. N.Y. Entomol. Soc.*, Vol. 64 (1956), pp. 165-171.

36. Treat, A.E., "The Metathoracic Musculature of Crymodes Devastator (Brase) (Noctuidae) with Special Reference to the Tympanic Organ," *Smithsonian Misc. Col.*, Vol. 137 (1959), pp. 365-377 and 16 plates.

37. Treat, A.E., and Roeder, K.D., "Electrical Response of the Noctuid Tympanum to Ultrasonic Stimulation," *Proceedings of 10th International Congress on Entomology*, Vol. 2 (1958), pp. 117-120.

38. Webster, F.A., "Mobility Without Vision by Living Creatures Other Than Man (with Special Reference to the Insectivorous Bats)," in J.W. Linsner (ed.) *Proceedings of the Mobility Research Conference*. New York: American Foundation for the Blind, 1962, pp. 110-127.

39. Webster, F.A., "Bat-Type Signals and Some Implications," in Bennett, Degan, and Spiegel (eds.) *Human Factors in Technology*. New York: McGraw-Hill, 1963.

40. Webster, F.A., and Griffin, D.R., "The Role of the Flight Membranes in Insect Capture by Bats," *Anim. Behav.*, Vol. 10 (1962), pp. 332-340.

XIII

REPORT OF WORKSHOP ON CLASSIFICATION OF CAUSES OF BLINDNESS

MODEL REPORTING AREA FOR BLINDNESS STATISTICS

NOVEMBER 29 - DECEMBER 1, 1962

A Workshop on Classification of Causes of Blindness, sponsored by the National Institute of Neurological Diseases and Blindness and under the technical direction of the National Society for the Prevention of Blindness, was held in Chevy Chase, Maryland, on November 29 - December 1, 1962. It consisted of a one-day session for State consulting and supervising ophthalmologists followed by a two-day session for State causes of blindness coders. It was believed desirable by both the National Society and by the Biometrics Branch to hold separate sessions for ophthalmologists and coders rather than have them jointly. This belief was based on the supposition that it would be better to get comments, pro and con, regarding the classification from the ophthalmologists in separate session and, thus, possibly avoid any effect of controversial discussion in this area on the coders.

In attendance on the first day were State consulting ophthalmologists from six of the ten Model Reporting States (Connecticut, Delaware, Louisiana, Massachusetts, North Carolina, and Vermont), as well as ophthalmologists in similar capacities from three non-Model Reporting Area States (District of Columbia, Ohio, and Oregon). On the second and third day, coders from all Model Reporting States (Connecticut, Delaware, Kansas, Louisiana, Massachusetts, New Hampshire, New Jersey, North Carolina, Rhode Island, and Vermont) as well as coders from two non-Model Reporting Area States (Ohio and Oregon) were present. On each of the days there were representatives from the National Society, the American Foundation for the Blind, and a number of Federal Agencies with blindness programs. These agencies were the Bureau of Family Services, Social Security Administration, Division of Services for the Blind (Vocational Rehabilitation Administration), and the Neurological and Sensory Disease Service Program (Division of Chronic Diseases, Public Health Service) and the NINDB. In addition a consultant in chronic diseases of the Chicago Regional Office, PHS, was present in view of his great interest in the Model Reporting Area and his help in stimulating States in his region to improve their blindness registers.

The first day's session was chaired by Dr. R.E. Hoover, ophthalmological consultant and member of the National Society's Committee on Operational Research which has been working on a revision of the Standard Classification of the Causes of Blindness. Mrs. Virginia S. Boyce, Assistant Executive Director, National Society, spoke on "National Society for the Prevention of Blindness Interest in Cause of Blindness Statistics." She pointed out that reliable statistical information on causes of blindness and partial sight is vitally needed by the National Society as a basis for planning program activities, and that the Society's public education and information program is directed to stimulating the public to seek regular eye care as a preventive measure. To emphasize and strengthen this message, the Society must use statistics on the extent of blindness caused by cataracts, glaucoma, diabetes, and other diseases. Among the child age groups one must know how many have lost some vision from amblyopia, crossed eyes, etc.

According to Mrs. Boyce, the Society must rely on the figures to measure progress being made in controlling blindness. For example, studies of causes of blindness among children of school age for over 20 years have shown a marked decrease in blindness due to infectious diseases. There has been a significant reduction in eye accidents as a cause of blindness among children--probably due to control of firearms and other dangerous toys and to various educational programs.

Almost daily the Society is called on for statistics to be used in various scientific presentations, such as supporting material for research grant applications and for papers to be published in ophthalmological journals and other professional media. With the able guidance and sound advice of Dr. Ralph G. Hurlin, the Society has over the years developed estimates of prevalence of blindness. These have been most valuable in answering some of the above needs.

Because the Society relies so heavily on statistical information for planning the direction of the blindness prevention program and for measuring the results, it was delighted to learn about the plan for a Model Reporting Area for Blindness Statistics. This project provides the means for gathering up-to-date causes of blindness data from a significant population group which will serve as an adequate basis for national estimates on causes. The Society has participated in the project through the Model Reporting Area's Planning Group and through assistance with the plans for this workshop.

The National Society has sponsored the Standard Classification of Causes of Blindness since its development in the early 30's by the Committee on Statistics of the Blind under the chairmanship of Dr. Hurlin. Its use has been promoted by the Society both nationally and internationally.

Mrs. Boyce urged states to call upon the Society for any help or guidance which they might need in use of the Classification of Causes of Blindness.

Dr. Hyman Goldstein, Chief, Biometrics Branch, National Institute of Neurological Diseases and Blindness, spoke on "The Model Reporting Area for Blindness Statistics," describing its purposes, standards, and program. The Area is a voluntary association of States which maintain registers of blind persons, and which have joined together in a pioneering and cooperative effort to collect uniform information so as to arrive at comparable and meaningful statistics on blindness that would benefit the States themselves as well as the nation as a whole. The Area is sponsored by the NINDB, with the counsel and the cooperation of the National Society for the Prevention of Blindness, the American Foundation for the Blind, and the Division of Chronic Diseases of the Public Health Service.

Dr. Goldstein indicated that the two basic objectives, to which each member State subscribes and agrees to uphold, are to make better statistics available on blind persons and to stimulate research in the field of blindness. As a basis for achieving these objectives, the Model Reporting Area will:

1. Encourage complete reporting of the blind, so that the number registered may more nearly reflect the true prevalence of blindness, and so that additions to the register may more nearly reflect the true incidence;

2. Seek to improve the records concerning the reported blind, so that the causes of blindness and the characteristics of the blind may more easily be studied;

3. Use a common definition of blindness and standardize recording of essential information, so that data from different states can be more meaningfully compared or pooled in an effort to arrive at national statistics on blindness;

4. Disseminate statistics derived from the registers, so that data may be readily available to all who are interested in the problems of blindness.

Each member State pledges to maintain the Area's standards which are as follows: (A) the use of a common definition of blindness; (B) an attempt by each State to include on its registers all residents who fall within this definition, whether or not such esidents have applied for services; (C) an attempt to collect certain specified items f information on all registrants as well as to clarify ambiguous reports and obtain data issing from incomplete reports. These data are: (1) date of addition to the Model eporting Area register; (2) type of addition (whether first addition or readdition); 3) county of residence (or its equivalent); (4) date of birth; (5) sex; (6) race; 7) age at onset; (8) date of eye examination; (9) discipline of examiner; (10) degree of vision; (11) the cause of blindness; (12) date of removal from Model Reporting Area egister; and (13) reason for removal; (D) each member State promptly corrects the essential items on its register in accordance with any reports received of re-interviews or re-examinations of registrants, and immediately removes from the Model Reporting Area register any person known to have died, moved out of State, or recovered vision beyond the Model Reporting Area definition of blindness. It also redetermines the residence of blindness status of every person on such register during an annual clearance or up-dating; (E) specified annual tabulations are prepared for submission to the NINDB.

The Biometrics Branch, NINDB, will make all efforts to aid and encourage states throughout the country to meet the above standards for membership in the Model Reporting Area so that they may each play a greater and more significant role in helping to determine the extent and nature of blindness as a national health problem, with ultimate benefit for the prevention, control, and treatment of blindness.

Dr. Goldstein emphasized that the present workshop was, in his opinion, the first of a number of such training sessions to be held so that there would be some uniformity in classification. Such workshops would help to guarantee the comparability and poolability of classification data from State to State in the Area. Good information on causes of blindness alone would more than justify the efforts and time being spent in developing the Model Reporting Area.

Mrs. Elizabeth M. Hatfield, Consultant in Statistics of the National Society, who, together with Dr. Goldstein, had planned the workshop, spoke at both sessions on the "Purpose and Plan of the Workshop." She indicated that the purpose of this first workshop was to introduce the tools to be used in coding causes of blindness and to provide special instructions in classification procedures to the members of the Model Reporting Area. It was deemed appropriate by Mrs. Hatfield that the workshop was under the technical direction of the National Society because the Society has long been concerned with the need for good statistics on causes of blindness. Such statistics are essential for sound planning of programs for the prevention of blindness.

The production of comparable statistics on causes of blindness, according to Mrs. Hatfield, is dependent basically on the use of a standard classification system. However, this is not enough. There must also be instructions and rules to insure that the classification is used in a uniform way by everyone. Without such complete instructions there are many possibilities for different interpretations and decisions regarding code assignments. A workshop seemed to be the best approach to provide instructions and an opportunity to discuss classification procedures and problems. A number of States represented at the workshop have had experience coding causes of blindness through use of one of the revisions. Others have used an abbreviated classification of their own device or have not even attempted to classify causes of blindness. The only instructions issued by the National Society for the Prevention of Blindness have been those to accompany the 1940 revision. A new manual is in process of preparation.

Mrs. Hatfield stated that originally the workshop was conceived as a training program only for the persons responsible for coding the causes of blindness. However, the State supervising or consulting ophthalmologists have a very important role in the development of good cause statistics. Coders need guidance and supervision from an ophthalmologist. Ophthalmologists need to be familiar and understand the classification. Therefore, it was decided to invite the ophthalmologists to attend a one-day conference prior to that for coders. The purpose of the conference was to acquaint them with the tools that have been developed to assist in classifying causes of blindness and the principles of the classification system as well as to secure their understanding and cooperation.

The Standard Classification developed over the last 30 years by the National Society's Advisory Committee on Operational Research, formerly the Committee on Statistics on the Blind, will be used in coding causes of blindness. A sub-committee of this committee has spent many months studying and considering the problems of classifying causes of blindness and developing tools for this purpose. Recent work on the revision of the classification has been spurred on by the needs of the Model Reporting Area for a workshop on the classification to be used in coding.

The programs planned for both the ophthalmologists and coders were similar. It was desired to keep them as informal as possible and the participants were encouraged to feel free to ask questions and make suggestions. Workshop plans called for presentations of the basic tools to be used in the classification procedure at both sessions.

On the first day Dr. Hoover discussed the "Role of the State Ophthalmologist in Classification." He indicated that it isn't easy to provide service to blind people when the vision range is from "no light perception to 20/200." Although there are many different ideas about what should be done and where one should start, everyone agrees that one area where it is possible to help is in uniform methods of reporting. The ophthalmological profession is one profession that has an opportunity to do really objective measuring. It is not difficult to put down the actual measurement of visual acuity. In addition to a uniform method, there is a need for accuracy. Sometimes the ophthalmologist is not too accurate in the data that he provides for statistics unless he is sure it will be put to good use. Some day, in Dr. Hoover's opinion, there will be an ophthalmologist on the staff of each State who will assume the major responsibility for having uniformly recorded diagnoses for coding and who will see that accurate data is relayed to the coder. Dr. Hoover asked the ophthalmologists in what areas did they believe they could encourage the examining ophthalmologists to be more particular in examination and in recording accurately data from such examinations.

Comments from the ophthalmologists present indicated that the problem is one mainly of educating the examining ophthalmologists as to the need to get accurate and codable ophthalmological data in order to end up with meaningful statistics. One problem related to the fact that under the Social Security Act a person can be certified as blind by either an ophthalmologist or optometrist. According to Dr. Hoover, however, this would still allow a State supervising ophthalmologist to request an ophthalmological report on an individual who has been examined by an optometrist.

Dr. Ralph G. Hurlin, Chairman, National Society's Committee on Operational Research, addressed both sessions on the "Revised Standard Classification of Causes of Blindness." He stated that the purpose of the Committee on Statistics for the Blind, appointed as a joint committee of the National Society for the Prevention of Blindness and the American Foundation for the Blind in 1930, was to create and improve statistics of all sorts on the blind. There was very little interest in such statistics at that time outside the Committee. Only three States previously had attempted any study of causes of blindness and they all did it only on a current basis. The Committee worked then on several types of statistics, the items that should be on an eye examination form, and the problems of classifying causes of blindness. In 1931 a proposed Standard Classification of Causes of Blindness was drawn up, published, and distributed to ophthalmologists for criticisms and suggestions. Etiological and pathological terms were reviewed. Two years later the Committee enlisted the help of 20 schools for blind children and had their cooperation in making annual reports. At the end of 1934 they presented a tabulation on causes of blindness of the pupils in these 20 schools, classified according to what is now called the Standard Classification of Causes of Blindness. By 1939 the Committee had prevailed on the Bureau of Public Assistance of the Social Security Administration to sponsor a study of causes of blindness among recipients of Aid to the Blind.

It was agreed that a Federal office would handle the study but that it would be entirely voluntary. Twenty-one states participated. About 2100 cases were contributed for the study. Cause data were analyzed, coded and tabulated and a report was prepared.

For this study, some changes in the classification were made. A further revision of the classification was published in 1957. Since the earlier revision, other causes had attracted enough attention to be put into the new revision. The Committee received a great deal of assistance from Dr. Arnold Sorsby's experience on statistics on causes of blindness in England and Wales. Numerous categories that he found useful were included in the revised classification. The eye examination report form, which the Committee recommended, relied upon the physician to indicate that eye affection which was primarily responsible for the impairment of vision and the etiology which underlay that affection. There was, thus, a two-fold classification of visual impairments: (1) classification with respect to site and type of affection and (2) classification with respect to underlying cause of blindness. Almost as soon as the 1957 revision was distributed, interest developed internationally for an international classification of cause of blindness. A Committee of the International Association for the Prevention of Blindness was appointed to recommend a classification. There was considerable correspondence and effort made to arrive at an agreement as to what categories should be considered for inclusion. That effort resulted in the 1960 classification which included relatively few changes. Since publication of the 1960 revision, the Model Reporting Area for Blindness Statistics came into being. It was felt that the 1960 classification was the most desirable for use in providing statistics on causes of blindness for the reporting area. The Committee then appointed a Sub-Committee to prepare procedures that could be used by the Model Reporting Area and recommended for use in other studies including those on school children which the National Society intends to continue. As the Sub-Committee started to work on procedures and to revise the earlier manual procedures, it found that it was dissatisfied with the 1960 revision. Because of the fact that the classification was scheduled for use by the Model Reporting Area, it was felt that some changes should be made before this happened. In the course of its work on the manual, the Sub-Committee also felt that the rather short Index of Diagnostic Terms, published in the older manual in 1940 for use in coding physician's reports, should be revised. This task has taken much longer than was originally anticipated. As work proceeded on the Index of Diagnostic Terms, other changes appeared necessary in the Standard Classification. Neither the revised classification nor the Index have, as yet, been published in view of the fact that they are still being examined for possible further changes. Both the classification and Index will relate not only to blindness but also to severe vision impairment.

Dr. Marta Fraenkel, technical consultant and member of the National Society's Committee on Operational Research, addressed both sessions on the "Index of Diagnostic Terms." She explained that the Index of Diagnostic Terms, relating to severe vision impairment and blindness, is the link between the numerous detailed diagnostic terms, as recorded by examining ophthalmologists, and the most recent edition of the Standard Classification of Causes of Blindness. The Classification consists of summarized terms for affection (site and type) and for etiology. Each type is completed by a code number.

The Index consists of an alphabetical listing of a large variety of diagnostic terms--including synonyms and eponyms--and of two columns labelled "affection code" and "etiology code" respectively. The code numbers listed in the columns are those of the category of the standard classification according to which the detailed diagnostic terms have to be coded.

The Index in its present structure permits the coder to translate the diagnostic entries of the physicians' individual reports into the terms of the standard classification. The Index, thus, contributes to the collection of uniform mass statistics which are a prerequisite of general analysis and evaluation of data on causes of blindness, as established in a variety of states. Since the present release of the Index was preliminary, the users of this release were asked to forward suggestions and recommendations based on their "test" experience.

The specific function of the Index of Diagnostic Terms is to advise the person assigned to process the medical report forms (the coder) about the assignment of the diagnostic terms entered by the examining physician as primary (main, antecedent) cause of blindness to the appropriate category of the Standard Classification of Causes of

Blindness. The Index thus is an essential link in the chain process which starts with the recording of the detailed and specific diagnostic terms and ends with quantitative data on types of affection and their underlying cause, presented in the categories of the Standard Classification. The coder receiving the examination reports, thus, is faced on each form with a two-part diagnostic statement; the terms used for listing both affection and etiology are specific and, hence, of a huge variety. The coder is expected to provide a two-part code according to the broad terms of the Standard Classification. The Index is the tool which guides him in this phase of processing.

The new Index is a single integrated list, presenting in alphabetical sequence all terms involved, that is, those of affection, of etiology, and of complete diagnoses. Each term is coded to the pertinent item for affection, or for etiology or, where pertinent, for both. Two parallel columns labelled "Affection code" and "Etiology code," respectively provide for the term in each line the pertinent code number(s).

The variety of possible diagnostic terms is enormous; in addition to English language terms--often popular as well as technical ones--scientific terms of Latin and/or Greek origin may be used and one, or even several, eponyms. Moreover, new terms are being introduced continuously; they either improve the specificity of the reference or describe newly established evidences.

An Index of Diagnostic Terms should--to be truly useful for a coder--be as complete and detailed as necessary; at the same time, it has to be a manageable tool which, in turn, requires that it is as concise as possible.

Any attempt that is made to arrange the selected items in a way which would simplify the busy and hurried coders' search for a term would make the Index streamlined and systematic. Among the three elements involved--site, type, and etiology--site has, wherever pertinent, been selected as the leading principle in the arrangement of the Index. Contrary to other indices, this Index does not "facilitate reference" to pertinent items in the classification but it constitutes, by virtue of the affection code and etiology code, the coding device as such. In other words, the worker coding the diagnostic terms of a medical report does not have to use the Standard Classification; the Index is--with very few exceptions--the only tool needed.

Dr. Fraenkel elaborated on the guidelines which were followed in the often difficult dilemma of inclusions and omissions. She spent some time in going over the thinking that guided the choice of a given selected code for a given diagnosis. Illustrations were taken at random from the Index and types of coding shown. She concluded by indicating that the Index, submitted to the members of the Model Reporting Area, would be undergoing its first test and, therefore, as in any test, shortcomings might be detected. She requested that any such shortcomings or suggestions for revision should be communicated to the National Society's Committee on Operational Research.

Mrs. Hatfield addressed both sessions on "Classification Procedure." In the discussion of classification procedures, suggestions and recommendations were made concerning methods for implementing coding operations and improving the quality and reliability of cause of blindness data. Illustrations of types of classification problems taken from actual eye examination reports were also presented for discussion.

The following points were emphasized by Mrs. Hatfield:

1. Both the supervising or consulting ophthalmologist and the coder have very important roles in the classification of causes of blindness and the development of good cause data. Classification of causes of blindness should be the responsibility of both the supervising or consulting ophthalmologist and coder with final responsibility resting with the former. The cause of blindness must be determined and the proper classification code assigned

on the basis of diagnostic information reported by the examining ophthalmologist. Since it is not always possible for the supervising ophthalmologist to review all cases of code assignments, the coder, working under his supervision and guidance, can do much of the routine work. Only problem cases would then require ophthalmological review and interpretation.

2. Eye examination report forms should be carefully reviewed and edited as soon as possible after receipt to determine the completeness and adequacy of the diagnostic information for classification purposes. This is necessary since eye reports are supplied by many different examiners and diagnostic information is often reported with varying degrees of adequacy. If a review is done regularly, as reports are received, it will be much easier to secure supplemental information, if necessary, from the examining ophthalmologists.

3. To improve both the quality and reliability of cause data, examining ophthalmologists should be queried for supplemental information whenever inadequate reports are submitted. The problem of classifying the cause of blindness is relatively simple when only one ocular affection and etiology is involved and it is the same for both eyes. Problems arise when more than one ocular affection is present and the examiner fails to designate which, in his estimation, is the cause of blindness. If it is not possible for the supervising ophthalmologist to make a reasonable determination of the cause of blindness from the reported diagnosis, then the examining ophthalmologist should be queried for clarification or additional information. The query program is a very important aspect of the classification procedure. It is one of the best ways in which the quality of reporting causes of blindness and the statistics derived therefrom can be improved. If the examining ophthalmologists provide unacceptable diagnostic reports, they have no way of knowing unless they are informed of this fact. This program can be an educational process for the ophthalmologists. It is only through being shown the need for better reporting and an understanding of what is required and for what purpose that ophthalmologists can be stimulated to do a better job. The understanding and cooperation of examining ophthalmologists can be secured by the supervising ophthalmologist in a number of ways, such as by meeting with them, by distribution of printed information regarding the program, reporting and classification procedures, by periodic reminders concerning the need for reporting, by brief summary reports of statistical information derived from the eye reports with an analysis of the problem and implications for prevention.

4. A good working relationship should be developed with the examining ophthalmologists. They should be informed and educated concerning the requirements for and the value of good statistics on causes of blindness.

5. A uniform system of reporting diagnostic information is essential to insure the comparability of cause of blindness statistics. When the present revision of the Standard Classification is completed and printed, copies will be made available for distribution to all ophthalmologists. It is also planned to develop a handbook of instructions for ophthalmologists which will explain reporting and classification procedures. In order that reliable and comparable statistics on causes of blindness can be compiled,

diagnostic information must be reported in a uniform manner. The type of information obtained is dependent upon the questions asked and the way in which the section on diagnosis on the eye examination report form is set up. In the development of the proposed report form, a great deal of thought was given to the type of information desired for classification purposes and the manner in which this should be requested from the examining ophthalmologist. Since it is the responsibility of the examining ophthalmologist to designate the cause of blindness, the section for diagnosis on the proposed form is designed in what is felt to be a logical way to guide the examiner in the proper designation of the underlying cause of blindness as defined. Present reporting of diagnosis does not lead to comparability of cause statistics. When one asks simply for "diagnosis" or "primary eye affection," the examining ophthalmologist cannot be expected to report the type of information desired for classification purposes. It is, therefore, recommended that each member of the Model Reporting Area for Blindness Statistics adopt a standard form of diagnostic report, conforming insofar as possible to section IV--Clinical Examination--of the eye examination report form proposed by the National Society for the Prevention of Blindness.

6. A quality control program is necessary in order to evaluate the comparability and reliability of diagnostic information and classification procedures. It is essential in the development of reliable statistics on causes of blindness. The purpose of this program is two-fold: (1) to evaluate the quality and comparability of reporting and coding in the member States, and (2) to provide information on coding problems which will be helpful in improving the classification tools and determining the need for special coding instructions. This program could best be implemented by submitting to the National Society for the Prevention of Blindness a monthly sample of coded eye examination reports for review and evaluation. These should be exact copies, identified by name or register number, of report for all new cases or the first 25, whichever is less, received each month. Any supplemental information requested to assist in classifying the cause of blindness should also be attached. In addition, it would be helpful to have reports for any other cases, not included in the sample, which present special classification problems. The coding will be reviewed promptly by the National Society and an evaluation report sent to each State. Any differences in classification will be accompanied by an explanation of the interpretation and proper coding for future reference. Those States planning to code causes of blindness for the entire register should send in a coded sample of the first 100 cases (those registered prior to 1963) for review. Subsequently a 10 percent sample of coded cases (every tenth case) should be submitted until coding of the entire register has been completed.

Following this presentation, Mrs. Hatfield discussed examples of various coding procedures and problems.

As mentioned above, the second and third day of the workshop were for the coders only. The morning session of the second day was chaired by Mrs. Boyce, the afternoon session by Dr. Goldstein. The second day consisted, in addition to the presentations mentioned above, by Mrs. Hatfield, Dr. Hurlin, Dr. Fraenkel, and Dr. Goldstein, of a lecture by Dr. Hoover on "Anatomy, Physiology, and Pathology of the Eye." This lecture, focussed by Dr. Hoover on a nonmedical, nontechnical level as much as possible, was very favorably received by the coders. It was accompanied by slides, blackboard drawings and reference book material. It was evident that Dr. Hoover was making very clear to the participants the meaning of terms with which they had been dealing for many years and which some of them barely understood. His exposition was very clear with respect to trying to show cause and effect relationships in the area of visual disabilities.

The third day of the workshop, under the chairmanship of Mrs. Hatfield, was devoted to further discussion of classification procedures and coding practice sessions. The coders had been requested, in advance, to bring with them a number of anonymous eye examination report forms that seemed to present problems to them. In addition Mrs. Hatfield had brought with her certain information derived from actual cases which presented difficulties in coding. These were reviewed in some detail and questions raised by the participating coders were discussed.

In retrospect, one must conclude that the workshop for the consulting ophthalmologists and the coders served a very useful purpose. This is confirmed by correspondence received after the workshop from representatives who attended from the States of Delaware, Kansas, New Hampshire, North Carolina, Ohio, Oregon, and Vermont. Furthermore, correspondence received from the National Society for the Prevention of Blindness indicated that, in the opinion of their representatives at the workshop, it was very successful. It is hoped that similar workshops may be held from time to time as the need warrants. It is felt that the beneficial effect of these workshops will increase and hopefully spread to other states that are not members of the Model Reporting Area.

XIV

EXCERPTS FROM THE PROCEEDINGS OF THE

WORKSHOP ON NOMENCLATURE OF COMMUNICATIVE DISORDERS
BETHESDA, JUNE 18-20, 1962

EDITOR'S NOTE:

Permission to publish the proceedings of this workshop in this issue of the RESEARCH BULLETIN has been graciously given the American Foundation for the Blind.

Under the sponsorship of The Rehabilitation Codes and with the support of funds from the National Institute of Neurological Diseases and Blindness, Communicative Disorders Research Training Committee (grant no. B-3676), a workshop on the nomenclature of communicative disorders was convened in Bethesda. Fifty-one persons participated: of these, forty-three are leading academic and clinical specialists in the general area of disorders of human communication; eight represented various governmental and professional agencies as official observers.

The purpose of the workshop was to expose the tentative material of the Impairment Code on Communicative Disorders to the deliberations of a critical, nationally representative group so that it could be further developed and refined. It seemed clear to the sponsors of the workshop that prior to any practical field-trial of the impairment code the material would have to be reviewed, edited, and accepted by the professional groups and individuals most concerned with the problems that the code encompasses. In a broad sense, the workshop was designed to aid communication about communicative disorders. The general goal was clearly achieved. At the end of three days of careful work the revised code material was accepted by general consensus in plenary session as a workable form for field trial, subject to revision in the various sections as field assessment and further sub-committee work continues in the future.

BACKGROUND

The Rehabilitation Code developed from studies begun six years ago within the framework of The Association for the Aid of Crippled Children in New York. As the problems and needs of communication among many professional groups were more clearly delineated, the designers of the original, quite limited, study were forced to consider an entire range of codification relative to rehabilitation, in terms of many aspects of impairment, disability, and handicap important to the health and welfare of affected persons and to the many techniques involved in the efficient and economic management of these problems.

Various agencies, groups, and individuals have participated in the design and development of the project. These include several federal and many professional agencies, many service and voluntary organizations, and a goodly number of colleges and university medical centers. Continued extensions of the project were implemented by support from the Association jointly with the federal Office of Vocational Rehabilitation. With the emergence of definite goals, based on data from field tests and surveys, and studied over three years by a group of ad hoc professional subcommittees, it became apparent that the achievement of an integrated system to encode the rehabilitation status, needs, and potentials of vast numbers of affected persons was an accomplishable end-product, both desirable and attainable.

Accordingly, The Rehabilitation Codes was set up in a separate office in 1961 with aya Riviere, D.Phil. (Oxon.) as director. Dr. Riviere had been the associate director ith Mr. Leonard Mayo, Executive Director of the sponsoring Association, and has been ssociated with the project from the outset in 1957. For a complete review of the roject, in both historical and current terms, reference is made to Dr. Riviere's five-ear progress report.*

The Committee on Communicative Disorders of The Rehabilitation Codes includes forty-wo participating and eight corresponding members, a national aggregate of specialists n audiology, speech pathology, etiology, laryngology, neurology, psychiatry, and sychology. It was formed in the spring of 1960, and met several times as a general roup during 1960-1961. Its primary objective was the development of a three-digit ystem of codification suitable for both the description of impairment and the retrieval f descriptive information pertinent to disorders of voice, hearing, speech, and language comprehension and use. Within the limits of the one thousand entry Impairment Code, this was to be accomplished by no more than one hundred three-digit entries. Secondary objectives included work on the development of one-digit and two-digit codes for pertinent reference to etiology and pathology, respectively. The general pattern of study began with a description of normal function and proceeded through the complex of disorders.

By the spring of 1961 it became apparent that the total committee was too large for the efficient consideration of details; accordingly, four sub-committees were formed to work out an impairment code relative to disorders of (respectively) voice, hearing, speech, and language comprehension and use. These sub-committees met at various times and in various places through the winter and spring of 1961-1962, and their work on a tentative draft for an Impairment Code for Communicative Disorders constituted the basic material for the agenda of this Workshop on Nomenclature of Communicative Disorders.

DISCUSSION

The final reports were accepted by the total group in general consensus. The status of the detail of the three-digit code varies considerably from one section to another. Relative to some topics, considerable work remains to be done; this applies particularly to the material on impairment of language comprehension and use.

The most important ingredient of any report of this workshop resides in its end product--the draft of the Impairment Code on Communicative Disorders as it presently stands (see Appendix). Several questions and ideas were developed from the experience of the participants in the work of the sub-committees and from the discussions in the plenary sessions.

Various participants expressed regret that the conference was limited to three days. This is particularly interesting in view of the difficulty in getting this number of persons to interrupt their regular work, and of the fact that the group "warmed up" very quickly and quite readily got to the business of the conference.

A few expressed discontent that they could not participate in more than one sectional group. Inasmuch as this was a very verbal group of participants with many and varied interests in the general area of communicative disorders, this attitude is understandable.

There was general concern about the amount of overlap in the technical detail between the concern of any one sub-committee and the concern of each of the other three. Without doubt, there is some redundancy that should be cleared away. This becomes a topic for the concern of the general Committee on Communicative Disorders which will continue its work with the codes.

---

*Rehabilitation Codes: Development and Field Testing of an Operational Tool for Serial Recording of the Rehabilitation Process: Five-Year Progress Report, 1957-1962. Rehabilitation Codes, 1790 Broadway, New York 19, N.Y.

It was refreshing, indeed, that so many of the participants who had not theretofore worked on the detail of the Impairment Code expressed the opinion that this kind of conference should have been held twenty years ago, and that a similar conference should be planned every five years: that, had this happened before, the entire field of communicative disorders would now be in a more healthy, less confused state than is now true.

Some attention is warranted, perhaps, to some of the particular problems of the various sub-committees as next described (see Appendix for the detail of code entry references).

Section on Impairment of Voice Function

This group worked very rapidly toward an acceptance of a general framework for their part of the code and moved readily through the detail. While there was much discussion, there was very little dissension on any of the three-digit categories. An exception has to do with Entry 213: the main term, "roughness" and its description obviously require further consideration. Because the group arrived so readily at a consensus, they were able to spend considerable time on the details of description. Agreement could not be reached about the meaning and implications of the term "stereotype"(Entry 211).

Section on Impairment of Hearing Function

This is the only one of the disorders wherein quite definitive clinical measurements are available. Accordingly, much of the detail of the three-digit entries is concerned with a quite precise description of the amount and kind of auditory dysfunction. There was clear agreement that measurements in terms of hearing for speech are basic. Entries 247-261 are included for use with the kinds of clinical problems for which the use of speech-hearing measurements is not possible. The group remained dissatisfied with the inclusion of Entries 267 and 268; the belief was clearly expressed that these items, referring to what is often called "a psychogenic overlay on organic hearing impairment," might better be coded under the section on Impairment of Psychosocial Function in the over-all Impairment Code.

Section on Impairment of Speech Function

There was a real problem in these deliberations in the differentiation between large categories of impairment and the pertinent descriptive detail. A major step in clarification was achieved with the use (and definition) of the key-term, "inappropriate" (i.e., for communication), as a principal qualifying adjective. Throughout the discussions, the participants had genuine difficulty in getting away from references to etiological and pathological aspects of impairments of speech; that they were at last able to do this testifies to the energy and determination of the group. Considerable time was devoted to the discussion of Entry 275, and, without doubt, this will require further study.

Section on Language Comprehension and Use

The deliberations of this section were the most divergent of all. This is understandable in view of the esoteric nature of the general topic. As is commonly true about most discussions of language, the language of the discussion generates "built-in" semantic and pragmatic confusions. There were real problems in attempting to codify a descriptive terminology that includes impairments of both children and adults. Many of the participants had great difficulty in differentiating their clinical procedures from the descriptive impairments in reference. The chairman felt the need on many occasions to reiterate that the work on the Impairment Code continues into the future. It is safe to report that few of the participants in this section were completely satisfied with the codification reported out from their sub-committee trial, yet the majority were willing to subject it to field-trial.

rojection

At a superficial glance the codes appear complex, but no more so than the array of uman states amenable to rehabilitation. It took considerable time in discussion for any of the participants to realize the scope and the limitations of the three-digit mpairment Code; and, further, to realize that the major three-digit categories are menable to expansion in whatever limitless descriptive detail any individual or group ishes to add by means of decimal subheadings to incorporate his own operational nterests.

It was difficult at the outset for many of the participants to try to think of mpairment as different from degree of disability, and from pathology and etiology. hese terms are specifically differentiated in the Rehabilitation Codes. With some ractice, however, these differentiations were quite well achieved by all the participants. At stake in this regard is the clear understanding that such a code as this must e built without regard for the symptom-complex exhibited by any particular patient. As he code is employed in describing patients, it will no doubt be necessary to combine ode-entries in multiples as descriptives of syndromes. There are various examples of his in the five-year progress report.

Considerable committee work remains for the future. The Impairment Code for Communicative Disorders will need extensive field-trial, and, in some sections, further revision. Overlaps must be reconciled before the eventual removal of organizational subdivisions among voice, hearing, speech, and language comprehension and use. A correlative two-digit code to identify the terms of pathology is required; as yet, little has been done in this regard except for the work of the sub-committee on impairment of hearing function. Finally, there must be a Manual which contains sufficient descriptive detail so that definitions are clear and so that indicated instrumentation, methodology, or other operational instructions are clearly specified.

William G. Hardy, Ph.D., Chairman
Workshop on the Nomenclature of Communicative
Disorders
Bethesda, Maryland
June 18-20, 1962

APPENDIX C

IMPAIRMENT CODE: COMMUNICATIVE DISORDERS

	IMPAIRMENT OF VOICE FUNCTION	Normal human voice is defined as the auditory experience of phonation which is culturally appropriate for communication.
	Absence/Total Loss of Normal Function	
200	Without substitute voice	
201	With substitute voice	
	Disorders of pitch	Pitch level refers to the central tendency of pitch (voice key) around which individuals' inflectional and intonational variations habitually occur.
202	Level too high for age and sex	
203	Level too low for age and sex	

	Disorders of loudness	Level refers to the central tendency or average loudness which is characteristic of an individual's speech.
204	Inadequate level	
205	Excessive level	
	Disorders of control	Variations in phonation which occur contrary to the conscious intent of the speaker.
206	Intermittent phonation	
207	Spasmodic variations of pitch and/or loudness	Pitch "breaks."
208	Tremor	
	Disorders of intonation	Habitual variability in pitch, loudness, and/or duration inappropriate to the meaning or the circumstances.
209	Insufficient variability	
210	Excessive variability	
211	Stereotypy	
	Disorders of quality associated with phonation	
212	Breathiness	Excessive escape of air.
213	Roughness	This includes such qualities as harsh, hoarse, grating, rasping, etc.
	Disorders of quality associated with resonance	
214	Hyper-nasality	A characteristic modification of speech suggesting an abnormal participation of the nasal resonators.
	IMPAIRMENT OF HEARING FUNCTION	Normal hearing consists of sensitivity to and transmission and recognition of sounds within appropriate environmental limits.
	Absence/total loss of normal function	
215	Monaural	
216	Binaural	

Reduction of sensitivity of hearing for speech

Hypoacusis; ranges based on sensitivity in decibels of hearing for speech, re. normal acuity. No punch = 0-15 db.

217	Right ear	A	16-26
218	" "	B	27-44
219	" "	C	45-66
220	" "	D	67-84
221	" "	E	85-100
222	Left ear	A	
223	" "	B	
224	" "	C	
225	" "	D	
226	" "	E	
227	Binaural	A	
228	" "	B	
229	" "	C	
230	" "	D	
231	" "	E	

Reduction of intelligibility for speech

Dyslogacusis; ranges based on discrimination score in percent of correct responses; test materials to be PB lists, as specified. No punch = 100-88%.

232	Right ear	A	86-80
233	" "	B	78-68
234	" "	C	66-58
235	" "	D	56-42
236	" "	E	40-0
237	Left ear	A	
238	" "	B	
239	" "	C	
240	" "	D	
241	" "	E	
242	Binaural	A	
243	" "	B	
244	" "	C	
245	" "	D	
246	" "	E	

Estimated reduction of hearing for speech

Ranges are the same as for 217-221; level in decibels based on the thresholds for pure tone in the speech-hearing range (preferably the average of thresholds at 500, 1000, and 2000 c.p.s.)

247	Right ear	A
248	" "	B
249	" "	C
250	" "	D
251	" "	E
252	Left ear	A
253	" "	B
254	" "	C
255	" "	D
256	" "	E

	Estimated reduction of auditory sensitivity based on procedures NEC/NOS	Ranges are the same as for 217-221. NEC/NOS = "not elsewhere covered"; "not otherwise specified." Specify procedure.
257	Binaural A	
258	" " B	
259	" " C	
260	" " D	
261	" " E	
	Distortion of hearing function	Dysacusis; distortion in audition in ways not accountable in terms of loss of sensitivity
262	Monaural	
263	Binaural	
264	Other distortion	Auditory disturbance not accountable in terms of dysacusis nor by reduction in sensitivity and/or discrimination.
265	Lowered tolerance for sound	Dynacusis
266	Impairment of ability to localize sound	Dysstereoacusis
	Apparent disturbance of hearing function	Psychomalacusis
267	In addition to demonstrable organic impairment of hearing	
268	Without demonstrable organic impairment of hearing	

IMPAIRMENT CODE: COMMUNICATIVE DISORDERS

	IMPAIRMENT OF SPEECH FUNCTION	Normal speech is the oral and verbal expression of language appropriate to the environment of the speaker and the listener. The term "inappropriate" is used throughout from the reference point of the listener.
269	Absence/total loss of speech function	
270	Impairments of articulation	Inappropriate phonation and/or omission and/or substitution and/or distortion of speech sounds.

271	Inappropriate disfluencies	Inappropriate pauses; prolongation of sounds; revision of speech elements; interpolation of extraneous speech elements; repetition of sounds, syllables, words, and/or phrases; for example, as in stuttering, cerebral palsied speech, etc.
272	Inappropriately fast	
273	Inappropriately slow	
274	Inappropriately varied	Monotony or excessive or uncontrolled variability.
275	Impairments in the patterning and/or control of stress in syllables, words, and/or word-groups	"Stress" refers to the semantic and/or mechanical variations in time, intensity, frequency, etc. at certain points within connected discourse.
276	Impairments of concomitant audible behavior	That is, clicks, smacking, nasal emission of air, etc., as in speech associated with cleft palate.
277	Impairments of concomitant visible behavior	Lack of movement normally accompanying speech, as in the faces of Parkinson's disease; or in the lack of facial movement associated with childhood autism; and/or inappropriate movements, such as eye-blinking in stuttering, or grimacing in cerebral palsied speech.

IMPAIRMENT CODE: COMMUNICATIVE DISORDERS

	IMPAIRMENT OF LANGUAGE COMPREHENSION AND USE	Normal language is a system of communication among human beings of a certain group or community using symbols possessing arbitrary conventional meanings.
278	Absence/total loss of language comprehension and use	Failure to develop, or loss of previously acquired, language skills; description would specify various aspects of receptive, integrative and expressive dysfunction.
	Limitation of language unrelated to comprehension	Receptive defects.
279	Impairment of the ability to process, pattern, and retain auditory stimuli unrelated to comprehension	
280	Impairment of the ability to process, pattern, and retain visual stimuli unrelated to comprehension	

281	Impairment of the ability to process, pattern, and retain tactile/cutaneous/kinesthetic stimuli unrelated to comprehension	
282	Impairment of the ability to process, pattern, and retain stimuli of other sense modalities	Gustatory, olfactory, thermal, etc.
	Limitation of language comprehension	Integrative defects.
283	Impairment of the ability to comprehend the meaning of discerned verbal auditory patterns	
284	Impairment of the ability to comprehend the meaning of discerned verbal visual patterns	
285	Impairment of the ability to comprehend the meaning of discerned verbal tactile/cutaneous/kinesthetic patterns	
	Limitation of the ability to formulate language	
286	Impairment of the ability to formulate meaningful verbal material spontaneously	
	Impairment of the ability of spontaneous expression	
287	Impairment of the use of motor patterns to express meaningful verbal/oral material	
288	Impairment of the use of motor patterns for graphic representations	
289	Impairment of the use of motor patterns for gesture/pantomine/facial expression	
	Limitation of the ability to imitate linguistic patterns	
290	Impairment of the ability to imitate, i.e., reproduce, a discerned linguistic auditory pattern, the input and output pathways being considered intact	
291	Impairment of the ability to imitate, i.e., reproduce, a discerned linguistic visual pattern, the input and output pathways being considered intact	

92 Impairment of the ability to imitate, i.e., reproduce, a discerned linguistic tactile/cutaneous/kinesthetic pattern, the input and output pathways being considered intact

Limitation of the ability to imitate non-linguistic patterns

293 Impairment of the ability to imitate, i.e., reproduce, a discerned non-linguistic auditory pattern, the input and output pathways being considered intact

294 Impairment of the ability to imitate, i.e., reproduce, a discerned non-linguistic visual pattern, the input and output pathways being considered intact

295 Impairment of the ability to imitate, i.e., reproduce, a discerned non-linguistic tactile/cutaneous/kinesthetic pattern, the input and output pathways being considered intact